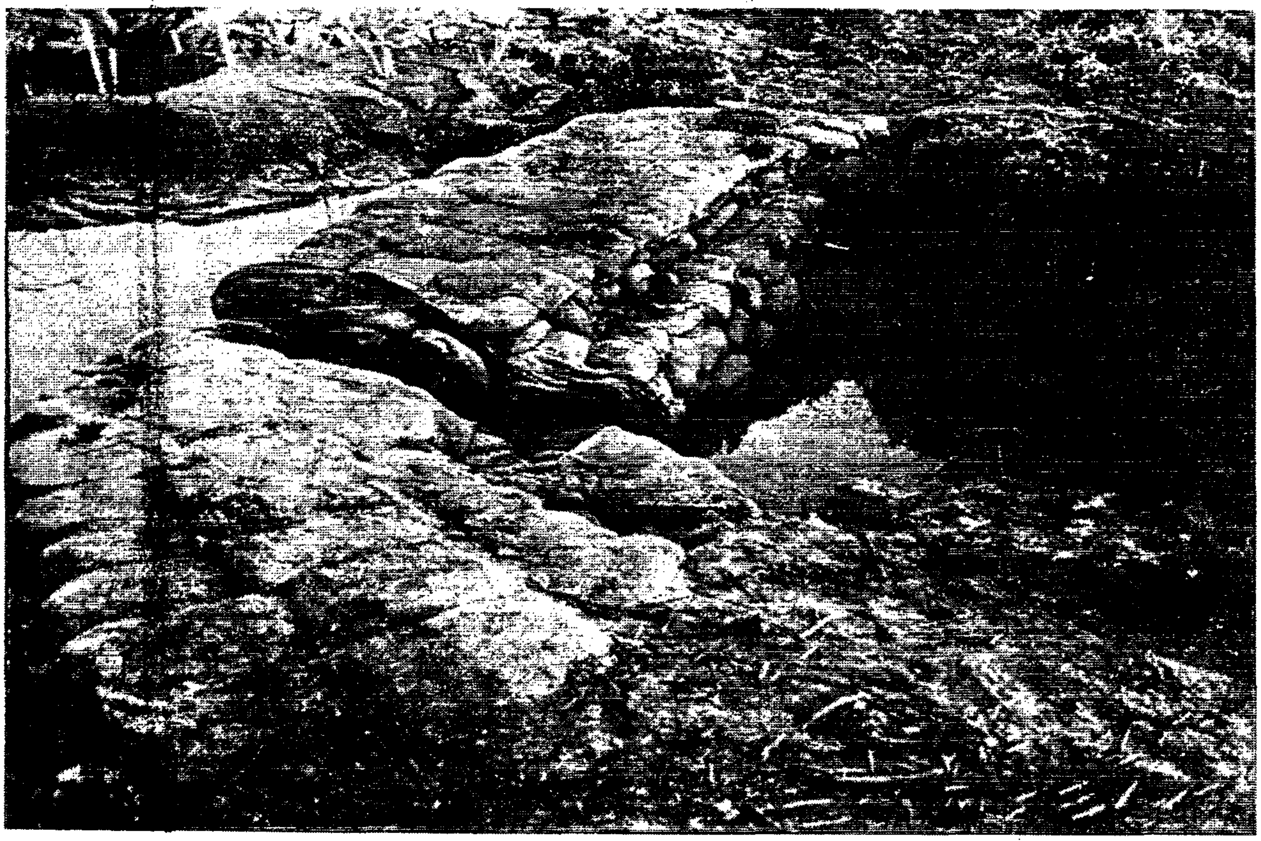
SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION

Initial Appraisal Report – Lower Sacramento Area



US Army Corps
of Engineers

Sacramento District
South Pacific Division

October 1993

C-103337

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, SACRAMENTO
CORPS OF ENGINEERS
1325 J STREET
SACRAMENTO, CALIFORNIA 95814-2922

REPLY TO
ATTENTION OF

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION

Initial Appraisal Report - Lower Sacramento Area

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SYLLABUS

The Sacramento District, Corps of Engineers, has been authorized to conduct a comprehensive analysis of the long-term integrity of the levee system for the Sacramento River Flood Control Project. The project was authorized by the Flood Control Act of March 1917 and modified by various Flood Control and/or River and Harbor Acts in May 1928, August 1937, and August 1941. Additional modifications on Sacramento River and tributaries were authorized by the Flood Control Acts of December 1944 and May 1950 and incorporated under Sacramento River and Major and Minor Tributaries. Although construction of the project was initiated in 1918, many of the levees were originally constructed by local interests prior to that time and subsequently modified and adopted as part of the project. The Reclamation Board has participated as the local sponsor of the project and is responsible for the operation and maintenance of project facilities.

This report is the fourth phase of the comprehensive analysis. About 295 miles of project levees along the Sacramento River and tributary sloughs, the Yolo Bypass, and portions of project levees on Cache Creek, Willow Slough Bypass, and Putah Creek were evaluated. Generally, the study area is south of the Sacramento Urban Area and covers portions of Sacramento, Solano, and Yolo Counties. The project levees on Cache Creek, Willow Slough Bypass, and Putah Creek are west and north of Sacramento and were transferred from the third phase into the fourth phase at the request of The Reclamation Board.

Studies indicate that sections of the project levees are susceptible to seepage, subsidence, and stability problems and do not provide the design levels of flood protection. Potential problems are primarily the result of sandy soils within the levee embankment and foundation. About 47 miles of reconstruction work is required to meet project design requirements at an estimated cost of $70.4 million. About 18 additional miles of levees along Cache Creek, Willow Slough Bypass, and Putah Creek may need reconstruction work to restore levee crown elevations. Subsidence due to ground-water pumping appears likely to have caused levee subsidence, but additional studies by the local sponsor are needed, since there is no Federal interest at this time if deficiencies are caused by non-design defects. About 6,000 people reside landward of the levees that need reconstruction (excluding Cache Creek, Willow Slough Bypass, and Putah Creek); damageable property in those areas is estimated at $460 million.

The Federal interest in levee reconstruction at this time is limited to work that is economically justified. By using this criteria, 2.4 miles of levee would be recommended for reconstruction at a first cost of $2.43 million.

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
INITIAL APPRAISAL REPORT - LOWER SACRAMENTO AREA

SYLLABUS

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CHAPTER I - INTRODUCTION

STUDY AUTHORITY

The Conference Report accompanying the Energy and Water Development Appropriation Act, 1987 (Public Law 99-591) included funds under Operation and Maintenance, General Appropriation, Inspection of Completed Works, for evaluation of the flood control system for the Sacramento River and its tributaries. Both the House of Representatives and Senate versions of the Conference Report contain similar language.

The House of Representatives Report, 99-670, is quoted as follows:

> *Inspection of Completed Works: Sacramento River Flood Control Project, California.* - The Committee has included $600,000 for a comprehensive analysis of the long-term integrity of the flood control system for the Sacramento River and its tributaries in collaboration with the State of California. The Committee is aware that even before the recent flooding, regional flood control officials felt the need for a thorough survey of the system. While it did serve well in the floods and prevented billions of dollars in damages, under stress it validated concerns that in many places remedial work is necessary as soon as possible, as may be enhanced levels of protection. The Corps is directed to report back to the Committee on protection enhancement requirements which it encounters in the review of the project.

The Senate's Report, 99-441, states the following:

> *Inspection of Completed Works, Sacramento River Flood Control Project, California.* - The Committee is aware of the need for a comprehensive analysis of the integrity of the flood control system for the Sacramento River and its tributaries. Given the importance of this flood protection system, the Committee believes that such an analysis is warranted.

By letter dated 9 September 1986, Robert K. Dawson, the Assistant Secretary of the Army, Civil Works, informed the Director of the California Department of Water Resources that the Corps of Engineers had commenced a five-phase evaluation of the levee system for the Sacramento River Flood Control Project.

The first two phases of the evaluation included the Sacramento Urban Area and the Marysville/Yuba City Area, the most heavily populated project areas. Resulting reports are entitled "Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Sacramento Urban Area," May 1988, and "Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Marysville/Yuba City Area," January 1990.

The third phase focused on the Mid-Valley area, including portions of the Yolo and Sutter Bypasses and levees on the Sacramento, Feather, and Bear Rivers which had not been considered in the second-phase report, as well as project levees on Yankee Slough and Dry Creek. A report entitled "Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Mid-Valley Area" was completed in December 1991.

The Lower Sacramento Area, or Delta area, is the fourth phase of the five-phase evaluation. It includes project levees on the Sacramento River south of the Sacramento Urban Area (including West Sacramento) and levees west and north of Sacramento along Cache Creek, Willow Slough Bypass, and Putah Creek. (See Plates 1 and 2.)

The fifth and last phase will be an evaluation of the Upper Valley Area from Knights Landing on the Sacramento River north, including tributary levees on Elder and Butte Creeks.

STUDY PURPOSE AND SCOPE

This study was conducted to evaluate the integrity of and level of flood protection provided by the existing Sacramento River Flood Control Project levees, to determine whether the levees currently function as designed and, if levee reconstruction is needed, to determine the Federal interest in proceeding with construction. The existing levee embankments of the Sacramento River Flood Control Project were constructed based on (1) a design discharge or channel capacity, (2) a design water-surface profile, and (3) a minimum freeboard requirement above the design water-surface profile (as authorized by the Flood Control Act of 1917). In general, the study objective was to develop reconstruction plans such that the project levees could safely pass the design flow (according to existing Corps criteria and guidance) at the design water surface.

OTHER STUDIES AND REPORTS

The Sacramento District has several studies ongoing in the Lower Sacramento Area, Phase IV, of the Sacramento River Flood Control Project. These studies include a Section 205 reconnaissance study for the city of Isleton on Brannan-Andrus Island (draft, October 1993); a special study for the

Sacramento-San Joaquin Delta, California (March 1993); an environmental restoration project, "Yolo Basin Wetlands, Sacramento River, California," in the design stage; an environmental restoration project, "Yolo Basin Wetlands, Davis Site," in the planning stage; and a reconnaissance report for the Westside Tributaries to Yolo Bypass (due for completion in 1994).

Reports pertinent to the Sacramento River Flood Control Project system, Yolo Bypass, the Sacramento River Deep Water Ship Channel, and the Delta area are briefly described in Table 1.

The State of California, Department of Water Resources has a number of ongoing studies in the Sacramento-San Joaquin Delta. Part of these ongoing studies, which include flood control, are:

- Increasing floodflow capacities by dredging and widening channels to allow more unrestricted flows.

- Building new setback levees to provide greater flood protection for Thornton, Walnut Grove, Tyler Island, and other areas.

- Controlling subsidence and soil erosion on Sherman and Twitchell Islands by altering land use to provide wildlife and waterfowl habitat.

- Seismic stability studies.

- Water transfer studies.

- Subsidence monitoring studies.

TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE
SACRAMENTO RIVER FLOOD CONTROL SYSTEM, LOWER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
U.S. Army Corps of Engineers, Sacramento District	Levee and Channel Profiles, March 1957.	Developed design water surface profiles for each levee reach of the Sacramento River Flood Control Project.
	Report on Floods of February-June 1958, Sacramento-San Joaquin-Tulare Lake Basins, California, November 1958.	Presents data on flooded areas and flood damages along the main stem of the Sacramento River.
	Review Report on Cost Allocation for Flood Control, Oroville Project, Feather River, California, 15 February 1960.	Contains a study of and criteria for operating the flood control storage needed in Oroville Reservoir, evaluation of the flood control and other project benefits, estimate of project costs and allocation to its various functions, and determination of the justifiable contribution to the State of California in the interest of flood control.
	Oroville Dam and Reservoir, Feather River, California; Report on Reservoir Regulations for Flood Control, October 1970.	Report covered conditions which include Oroville Reservoir and New Bullards Bar Reservoir as well as descriptive information about the project, the method of operation, and the prescribed regulations for flood control operation.
	Report on the January 1970 Floods, Sacramento River Basin, California, January 1971.	Summarized rain floods in the Sacramento River Basin during the latter part of January 1970. Presented information on precipitation, runoff, flood damage, and the effects of existing and potential flood control works on floodflows and flood damages.
	Cache Creek Basin, California, Feasibility Report and Environmental Statement for Water Resources Development, February 1979.	Investigated flood, sediment deposition, and related water resources problems in Cache Creek Basin, including a flood problem on the rim of Clear Lake in the Upper Cache Creek Basin and a sediment control problem in Lower Cache Creek Basin.
	Sacramento River Deep Water Ship Channel, California, Feasibility Report and Environmental Impact Statement for Navigation and Related Purposes, July 1980.	Investigated the need for deeper draft channels to the Port of Sacramento to improve transportation of commodities to and from the Port, improve the safety and usefulness of existing channels, and enhance existing environmental and recreational conditions in the study area.

TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE
SACRAMENTO RIVER FLOOD CONTROL SYSTEM, LOWER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
	Draft Feasibility Report and Draft Environmental Impact Statement, Sacramento-San Joaquin Delta, California, October 1982.	Investigated water resource-related problems in the Sacramento-San Joaquin Delta to determine the need for and feasibility of improvements.
	Sacramento River and Tributaries, Bank Protection and Erosion Control Investigation, Sediment Transport Studies, rev. August 1983.	Described and evaluated potential erosion control measures that could be used in the Sacramento River basin. Determined sediment deposition in Yolo and Sutter Bypasses.
	Design Memorandum No. 1, Sacramento River Deep Water Ship Channel, General Design Memorandum and Appendix A and Final Supplemental Environmental Impact Statement, March 1986.	Presents the selected plan for navigation channel modification between New York Slough and the Port of Sacramento.
	Report on the February 1986 Floods, Northern California and Northwestern Nevada, January 1987.	Documented the hydrologic, physical, and economic damage data of the February 1986 rainfloods in Northern California and northwestern Nevada.
	Late Cenozoic Tectonism of the Sacramento Valley, California, 1987.	Indicates the potential for displacement along the Zamora Fault in the area of Cache Creek, Willow Slough Bypass, and Putah Creek.
	Design Memorandum No. 1, Cache Creek Basin, California, January 1987.	Describes modification to the Cache Creek Settling Basin.
	Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Sacramento Urban Area, May 1988.	Investigated the structural integrity of about 110 miles of Sacramento River Flood Control Project levees in the Sacramento Urban Area.
	Draft Report, Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 78-178) and Feather River (RM 0-28), June 1989; prepared by Water Engineering & Technology, Inc., for the Corps of Engineers.	Provided a detailed geomorphic analysis and bank protection alternatives report for the Sacramento River from Verona to Glenn and the downstream portion of the Feather River from the Sacramento River upstream to the confluence with the Yuba River.
	Oroville Dam and Lake, Feather River, California, Water Control Manual, Appendix IV to Master Water Control Manual, Sacramento River Basin, California, August 1989.	Provided a detailed plan for flood control and management at the Oroville Dam and Lake Project which is located on the Feather River about 5 miles east of the City of Oroville.

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TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE SACRAMENTO RIVER FLOOD CONTROL SYSTEM, LOWER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
	Geotechnical Assessments of Levees in the Mid-Valley Area, Sacramento River Flood Control System Evaluation, Roger Foott Associates, Inc., December 1989.	Documents the geotechnical assessment of over 250 miles of Mid-Valley levees, including portions of the Sacramento and Feather Rivers, the Yolo and Sutter Bypasses, and numerous tributary streams and smaller waterways.
	Office Report, American River and Sacramento Metro Investigations, California, Hydrology, January 1990.	Determines the level of protection provided by the Sacramento River and American River Flood Control Systems.
	Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Marysville/Yuba City Area, January 1990.	Evaluated about 134 miles of project levees along the Feather and Yuba Rivers and their tributaries in Butte, Sutter, and Yuba Counties.
	Report on Recommendations for Explorations, Further Study, and Laboratory Testing for the Preliminary Assessment of the Levees of the Lower Sacramento River Area, Phase IV, Sacramento River Flood Control System Evaluation, prepared by Harlan Tait Associates, April 25, 1990.	Presents recommendations for explorations, further study, and laboratory testing.
	Report of Findings, Subsurface Exploration for the Preliminary Assessment of the Levees in the Lower Sacramento River Area, Phase IV, Sacramento River Flood Control System Evaluation, Harlan Tait Associates, July 10, 1990.	Gathered geotechnical data to assess typical levee sections as related to levee seepage and landside slope stability; soil conditions of particular problem areas, and foundations conditions in terms of sustaining an increase in levee height.
	Levee Status, Mokelumne River, Approximate Stations 75+00 to 100+00, Roger Foott Associates, Inc., December 5, 1990.	Presents report on geotechnical investigation on the Mokelumne River Stations and the status of the levee and treatment options.
	Investigation and Treatment of Threatened Levees on Sherman Island, Roger Foott Associates, Inc., January 15, 1991.	Describes how, over 5 to 6 months in second half of 1990, levee problems developed on Sherman Island and were investigated and collective actions taken to mitigate their effects.
	Report on the Preliminary Geotechnical Assessment of the Levees in the Southern Portion of the Lower Sacramento River Area, Phase IV, Sacramento River Flood Control System Evaluation, prepared by Harlan Tait Associates, February 12, 1991.	Presents a preliminary geotechnical assessment of the levees in the southern portion of the Lower Sacramento River area.

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TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE
SACRAMENTO RIVER FLOOD CONTROL SYSTEM, LOWER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
	Appendix, Logs of Exploratory Borings Laboratory Test Results, February 13, 1991, accompanying Report on the Preliminary Geotechnical Assessment of the Levees in the Southern Portion of the Lower Sacramento River Area, Phase IV, Sacramento River Flood Control System Evaluation, prepared by Harlan Tait Associates, February 13, 1991.	Presents logs of exploratory borings and laboratory test results.
	Sacramento River Flood Control System Evaluation, Phases II-V, Programmatic Environmental Impact Statement/Environmental Impact Report, April 1991.	Describes alternative plans, resources in the area, potential impacts of the alternatives on resources, and mitigation strategies.
	American River Watershed Investigation, California, Feasibility Report, Appendix K - Hydrology, December 1991.	Presents results of studies on flooding problems along the American and Sacramento Rivers in the greater Sacramento area and identifies a plan to resolve the problems. Appendix K presents detailed hydrologic input for the study area.
	Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Mid-Valley Area, December 1991.	Evaluated about 240 miles of project levees along the Sacramento and Feather Rivers and their tributaries in portions of Placer, Solano, Sutter, Yolo, and Yuba Counties.
	Feasibility Report and Environmental Impact Statement/Environmental Impact Report, Sacramento Metropolitan Area, California, February 1992.	Evaluated the need for additional flood protection in the Sacramento Metropolitan Area that was not included in the American River Watershed Investigation, the alternatives to increase the level of flood protection, and the Federal interest.
	Yolo Bypass, California, Reconnaissance Report, March 1992.	Investigated flooding and related water resource problems associated with the Yolo Bypass in the north and Fremont Weir and Liberty Island in the south.
	Geotechnical Evaluation of Levees for Sacramento River Flood Control System Evaluation, Lower Sacramento River Area, Phase IV, February 1993	Presents geotechnical assessment of the levees in the Lower Sacramento River Area from Freeport to Collinsville.
	Office Report, City of Isleton, California, Section 205 Continuing Authorities, Basis of Design and Cost Estimates, Reconnaissance Level, March 1993.	Examines three alternatives for 100-year level of flood protection for Isleton with Geotechnical and Cost Estimate information.

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TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE
SACRAMENTO RIVER FLOOD CONTROL SYSTEM, LOWER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
	Draft Continuing Authorities, Section 205, Reconnaissance Investigation, City of Isleton, California, June 1993.	Examines 50-, 100-, and 300-year level of protection for Isleton.
Joint Report with the State of California	Sacramento-San Joaquin Delta, California, Special Study, Initial Report and Documentation Report, Volumes 1-5, March 1993.	Describes problems and opportunities to improve and/or provide flood protection, habitat, water quality, recreation, and navigation in the Lower Sacramento River area.
U.S. Department of Agriculture	Land Subsidence in the Sacramento-San Joaquin Delta, Literature Review, Sacramento, San Joaquin, and Contra Costa Counties.	A compendium of abstracts of articles reviewed in the scientific literature relating to land subsidence.
Federal Emergency Management Agency	Flood Insurance Study, Sacramento County, California, Unincorporated Areas, Volume 1 of 3, Revised September 30, 1988.	Investigates the existence and severity of flood hazards in the unincorporated areas of Sacramento County and aids in administration of the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973.
	Flood Insurance Study, Solano County, California, Unincorporated Areas, Volume 1 of 2, Revised September 27, 1991.	Revises and updates a previous Flood Insurance Study for the unincorporated areas of Solano County.
U.S. Bureau of Reclamation Mid-Pacific Region	Abstract, Subsidence of Peat in California and Florida, pages 395-420, Nikola P. Prokopovich, 1985	Describes land subsidence caused by biochemical oxidation of peat and peaty sediments in warm climates in California and Florida.
U.S. Geological Survey	Profile of Sacramento River, Freeport to Verona, California, Flood of February 1986, Open-File Report 88-82, 1988.	Documented the February 19 and 20, 1986, peak water-surface profile of the Sacramento River, peak discharges of the Sacramento and American Rivers, and data for five gaging stations located in a 33-mile reach between Freeport and Verona.
U.S. Department of Housing & Urban Development, Federal Insurance Administration	Flood Insurance Study, City of Woodland, California, Yolo County, April 1979.	Investigated the existence and severity of flood hazards in the City of Woodland, Yolo County, California.
State of California	Bulletin No. 192, Plan for Improvement of the Delta Levees, Bulletin No. 192, May 1975	Presents a plan for improving 310 miles of levees surrounding portions of 55 islands or tracts in the Delta and providing recreation facilities, improved roads, and environmental enhancement.

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TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE
SACRAMENTO RIVER FLOOD CONTROL SYSTEM, LOWER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
	Delta Levees - What is their future, September 1973.	Presents alternative courses of action for the Sacramento-San Joaquin Delta levees.
Department of Water Resources	Subsidence of Organic Soils in the Sacramento-San Joaquin Delta, August 1980	Identified subsidence areas in the Delta, determined the causes and amount of subsidence over given time periods, and determined feasibility of controlling the subsidence.
	California High Water, 1982-83, Bulletin 69-83, Department of Water Resources, July 1984.	Presents information on storms, flooded areas, and flood damages during the October 1, 1982, through September 30, 1983, water year.
	California High Water, 1985-86, Bulletin 69-86, Department of Water Resources, May 1988	Reports on high water and flood events and describes the State Flood Operations Center and its work during the February 1986 storm.
	The Floods of February 1986, Department of Water Resources' Public Information Office.	Describes the 1986 floods and their effects and aftermath.
	Sacramento-San Joaquin Delta Atlas, August 1987.	Provides background information on the Delta in a series of figures, photographs, and tables.
	Landslide and Flood Potential Along Cache Creek, Division of Mines and Geology, May 1990.	
Private	History of Development of the Sacramento River Flood Control Project, July 1969.	Presented a historical survey of the legal documents and political events leading to the construction and implementation of the Sacramento River Flood Control Project.

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HISTORY OF THE SACRAMENTO RIVER FLOOD CONTROL PROJECT

A short history of the Sacramento River Flood Control Project is contained in the Initial Appraisal Report, Sacramento Urban Area, dated May 1988. Additional pertinent information is contained in the report by Frank Kochis, 1969. The project is described, in general, in the following section.

EXISTING WATER RESOURCES PROJECTS

Federal

Sacramento River Flood Control Project. - The Sacramento River Flood Control Project was authorized by the Flood Control Act of March 1917 and modified by various Flood Control and/or River and Harbor Acts in May 1928, August 1937, and August 1941. Construction began in 1918 on this local cooperation project sponsored by The Reclamation Board, State of California. Various project components were completed between 1952 and 1958, and the final portion was completed in the mid-1980's. The project consists of a comprehensive system of levees, overflow weirs, outfall gates, pumping plants, leveed bypass floodways, and overbank floodway areas.

The project includes approximately 1,000 miles of levees, including 170 miles of levees on the Feather River and tributaries, providing flood protection to about 800,000 acres of agricultural lands; the cities of Colusa, Gridley, Live Oak, Yuba City, Marysville, Sacramento, West Sacramento, Courtland, Isleton, Rio Vista, and numerous smaller communities; transcontinental railroads; feeder railroads; airport facilities; and many State and county highways. Billions of dollars in flood damages have been prevented since the project was completed.

During major floods, upstream reservoirs intercept and store initial surges of runoff and provide a means of regulating floodflow releases to downstream leveed streamways, enlarged channels, and bypass floodways. In order to achieve the full benefits of the reservoirs, specific downstream channel capacities must be maintained. Reservoir operation is coordinated not only among various storage projects but also with downstream channel and floodway carrying capacities.

Operation and maintenance of the Sacramento River Flood Control Project is the responsibility of the State of California.

Shasta Dam and Lake. - Shasta Lake is a multiple-purpose project built by the Bureau of Reclamation and operated for flood control according to regulations prescribed by the Corps of Engineers. The dam, located on the Sacramento River near Redding, is a concrete gravity structure 602 feet high and

3,460 feet long. It creates a reservoir with a capacity of 4.5 million acre-feet, of which 1.3 million acre-feet are reserved for flood control during the winter season. In addition to providing flood control, the project provides for irrigation; municipal and industrial water use; power generation; fish and wildlife conservation; recreation; and sustained flow to improve shallow-draft navigation on the Sacramento River.

Shasta Lake is the key unit of the Central Valley Project, one of the most extensive water transport systems in the world. Shasta Lake operations have substantially reduced flood damage in the Sacramento River Basin.

Lake Berryessa, Monticello Dam. - Monticello Dam, located on Putah Creek near the town of Winters, is operated by the Bureau of Reclamation for irrigation, water supply, and recreation. Completed in 1957, the dam is 304 feet high, has a crest length of 1,023 feet, and impounds about 1.9 million acre-feet in Lake Berryessa. Although Lake Berryessa has no specific reservation for flood control, the project provides significant incidental flood control benefits as a result of the large volume of surcharge which can be stored. During flooding in 1964-65, runoff stored in Lake Berryessa reduced flows into the flood control channels. Maximum discharge since completion of Monticello Dam in 1957 was 18,700 cubic feet per second (cfs) for Putah Creek near Winters.

Cache Creek and Cache Creek Settling Basin. - Cache Creek originates at the Clear Lake outlet and flows through the Capay and Sacramento Valleys, through the Cache Creek Settling Basin, and into Yolo Bypass. Construction of the settling basin was completed by the Corps in 1937 as part of the Sacramento River Flood Control Project. The 3,600-acre settling basin, located in Yolo County about 2 miles east of Woodland, is bounded by levees on all sides. The fundamental purpose of the basin is to preserve the floodway capacity of the Yolo Bypass by trapping the heavy sediment load carried by Cache Creek.

Since construction in 1937, the basin has essentially filled, and sediment from Cache Creek is depositing downstream in flood control and navigation channels. The Corps of Engineers has contracted to enlarge the existing perimeter levees of the basin in order to provide 50 years of sediment storage capacity. The levees were raised by adding an average of 12 feet to the present levee height. In addition, the existing project levees were enlarged from the settling basin mouth upstream to County Road 102. To allow the entire basin to be used for sediment deposition, training levees were degraded and rebuilt adjacent to the western perimeter levee. Construction was initiated in August 1991. Enlargement of the existing perimeter levees of the basin was completed in September 1993.

Sacramento River Deep Water Ship Channel. - The Sacramento River Deep Water Ship Channel was completed in 1963. The 30-foot-deep channel was formed by widening and deepening existing channels from Suisun Bay to a point near Rio Vista and by excavating a new channel from that point to Lake Washington in West Sacramento. Rice and other grains, logs, wood chips, prepared animal feed, fertilizers, newsprint, and other commodities are transported by oceangoing vessels directly from the Pacific Ocean to the Port of Sacramento. In 1988, about 1.1 million tons was shipped through the channel. The 1985 Supplemental Appropriations Act authorized deepening the ship channel from 30 to 35 feet. The work is being accomplished in a series of six dredging contracts. The first contract was completed in 1989, and the second contract was completed in 1991. Due to financial constraints, contracts 3 to 6 remain on hold.

State of California

California State Water Project. - In 1959, the State Legislature enacted the California Water Resources Development Bond Act, which authorized the construction and operation of the State Water Project (SWP). The SWP facilities include 23 dams and reservoirs, 8 powerplants, 22 pumping plants, and 684 miles of aqueducts. These facilities are designed to readjust the imbalance of California's water resources and water needs.

Oroville Dam and Lake. - The major feature of the SWP is Oroville Lake, located 4 miles northeast of the city of Oroville. Oroville Dam was completed in 1967 and is the highest earthfill dam in the United States. The dam impounds a 3.5 million acre-foot reservoir, 750,000 acre-feet of which are reserved for flood control. Flood control operations are coordinated with New Bullards Bar Reservoir on the North Fork of the Yuba River according to rules prescribed by the Corps of Engineers.

The SWP conserves water in the Feather River Basin behind Oroville Dam and uses natural channels of the Feather and Sacramento Rivers and the Sacramento-San Joaquin Delta to convey water to the North Bay Aqueduct and the California Aqueduct. The North Bay Aqueduct is a 27-mile underground pipeline serving Napa and Solano Counties. The Harvey O. Banks Delta Pumping Plant, in the southern portion of the Sacramento-San Joaquin Delta, marks the beginning of the SWP's California Aqueduct. Water flows through Delta channels in the Clifton Court Forebay, then flows by gravity in an open canal to the Banks plant. At the Banks plant, the water is lifted 244 feet into the California Aqueduct, where it flows south by gravity to the San Luis complex in Merced County.

Yolo County Flood Control and Water Conservation District

Clear Lake Dam. - Clear Lake Dam, constructed in 1914 on the lower reach of Cache Creek for water supply, is owned and operated by the Yolo County Flood Control and Water Conservation District. The dam impounds 420,000 acre-feet. Water flows from Clear Lake through the 5-mile-long Clear Lake Outlet Channel through the Clear Lake Dam to Cache Creek.

Indian Valley Reservoir. - Indian Valley Reservoir is a multiple-purpose project located 11 miles upstream from the mouth of North Fork Cache Creek. Completed in 1975, the reservoir is also owned and operated by the Yolo County Flood Control and Water Conservation District. The 300,000 acre-foot storage capacity includes 40,000 acre-feet for flood control, the major purpose. Irrigation water is also provided to agricultural land in Yolo County. Since completion of Indian Valley Dam and Reservoir, the highest peak flow recorded for Cache Creek at Yolo was 33,000 cfs in January 1983.

Local Agencies

Local Drainage Facilities. - A system of canals is used to collect and channel surface water runoff from rainfall, irrigation, and other sources into pumping stations located near levee embankments within areas protected by the Sacramento River Flood Control Project levees and other local levees. These pumps are then used to pump water through or over the levee embankments into the Sacramento River, Yolo Bypass, Sacramento River Deep Water Ship Channel, Natomas Cross Canal, and other tributaries that make up the Sacramento River Flood Control Project system. Pumps are needed because water-surface elevations on the Sacramento River and tributaries during major floods are significantly higher than adjacent land surface elevations landward of the levees. The sump areas for the various pump stations have limited capacity; as a result, pumps run at or near peak capacity during major rainfall events in an effort to remove accumulated runoff. In addition, the city and county of Sacramento, Sacramento Regional Wastewater Treatment Plant, various other Reclamation Districts, and local entities pump from 100 to 2,000 cfs of water into the Sacramento River Flood Control Project system.

LOCAL PARTICIPATION

By letter dated April 5, 1990 (Attachment A), The Reclamation Board, State of California, has indicated intent to be the local sponsor for Phases II through V of the Sacramento River Flood Control System Evaluation. The Board will be responsible for fulfilling the non-Federal obligations required by the project works and will coordinate all activities, including cost sharing, with the responsible local entities. The Board also stated that the extent of the project works will be at least partially determined by the ability of local interests to fund their share of the work. In addition, the Board and Corps of Engineers, South Pacific Division, have agreed to the evaluation of Cache Creek, Willow Slough Bypass, and Putah Creek project levee reaches in this phase of the investigation (see letter dated July 3, 1990, Attachment A).

For this investigation, the State of California, in cooperation with the Corps of Engineers, provided February 1986 high-water mark information, surveyed levee crown profiles, surveyed levee embankment cross sections, and completed a report identifying past problem areas (due to high flood stages) of the levees.

CHAPTER II - STUDY AREA DESCRIPTION

EXISTING CONDITIONS

Environmental Setting and Natural Resources

Study Location. - The study area, located in Sacramento, Solano, and Yolo Counties, includes about 295 miles of Sacramento River Flood Control Project levees along Sacramento River and Yolo Bypass and their tributaries and distributaries. At the request of The Reclamation Board, evaluation of levees on Cache Creek, Willow Slough Bypass, and Putah Creek was transferred from Phase III (Mid-Valley Area) to Phase IV (Lower Sacramento Area). Locations of project levees are shown on Plate 2. Specific levees considered include the following:

- Cache Creek. - About 13.1 miles of levee along both banks from Road 102 to the upstream project levees. Levee heights range from 5 to 15 feet above the landside ground surface; crown widths are about 15 feet.

- Willow Slough Bypass. - About 15 miles of levee along both banks from the confluence with the Yolo Bypass to the upstream project limits. Levee heights range from 5 to 15 feet above the landside ground surface; crown widths are from 20 to 40 feet.

- Putah Creek. - About 16.3 miles of levee along both banks from the confluence with Yolo Bypass to the upstream project limits. Levee heights range from 10 to 15 feet above the landside ground surface. Crown widths are from 20 to 25 feet.

- Sacramento River. - About 43.7 miles of the east levee from Sherman Island upstream to Freeport Bridge and about 36.7 miles of the west levee from the confluence with Steamboat Slough upstream to the southern boundary of the city of West Sacramento. Levee heights range from 10 to 20 feet above the landside ground surface. Crown widths are from 25 to 50 feet.

- Yolo Bypass. - About 24.5 miles of the east levee from the confluence with Steamboat Slough upstream to the southern boundary of the city of West Sacramento and about 15.4 miles of the west levee from the southern limit of the levee within RD (Reclamation District) 536 upstream to the northern limit of the levee within RD 2068. Levee heights range from 15 to 30 feet above the landside ground surface. Crown widths are from 15 to 55 feet.

- Elk Slough. - About 19.2 miles of levee along both banks from the confluence with Sutter Slough upstream to the confluence with the Sacramento River. Levee heights are about 15 feet above the landside ground surface; crown widths are 15 to 30 feet.

- Sutter Slough. - About 13.2 miles of levee along both banks from the confluence with Steamboat Slough upstream to the confluence with the Sacramento River. Levee heights range from 15 to 20 feet above the landside ground surface; crown widths are 25 to 60 feet.

- Georgiana Slough. - About 24.1 miles of levee along both banks from the confluence with the Mokelumne River upstream to the confluence with the Sacramento River. Levee heights range from 10 to 15 feet above the landside ground surface; crown widths are 20 to 55 feet.

- Steamboat Slough. - About 22.6 miles of levee along both banks from the confluence with the Yolo Bypass upstream to the confluence with the Sacramento River. Levee heights range from 10 to 25 feet above the landside ground surface; crown widths are 25 to 60 feet.

- Miner Slough. - About 4.6 miles of levee along both banks between Yolo Bypass and Sutter Slough. Levee heights range from 15 to 30 feet above the landside ground surface; crown widths are 20 to 35 feet.

- Haas Slough. - About 11.6 miles of levee along both banks from the confluence with Cache Slough to the upstream project limits. Levee heights range from 10 to 15 feet above the landside ground surface; crown widths are 15 to 20 feet.

- Cache Slough. - About 6.2 miles of the east levee from the confluence with the Yolo Bypass upstream to the confluence with Haas Slough and about 4.8 miles of the west levee from the confluence with the Yolo Bypass upstream to the confluence with Ulatis Creek. Levee heights range from 10 to 20 feet above the landside ground surface; crown widths are 15 to 40 feet.

- Ulatis Creek. - About 3.1 miles of levee between Cache Slough and Lindsey Slough. Levee heights range from 10 to 20 feet above the landside ground surface; crown widths are 15 to 30 feet.

- Lindsey Slough. - About 13.5 miles of levee along both banks from the confluence with the Yolo Bypass to the upstream project limits. Levee heights range from 10 to 25 feet above the landside ground surface; crown widths are 12 to 55 feet.

- Threemile Slough. - About 7.6 miles along both banks between the Sacramento River and the San Joaquin River. Levee heights range from 10 to 15 feet above the landside ground surface; crown widths are 20 to 25 feet.

Existing project levee embankments around the Cache Creek Settling Basin were modified under the authorized Corps of

Engineers project for flood control, Cache Creek Basin (see Design Memorandum No. 1, "Cache Creek Basin, California," Corps of Engineers, January 1987). Under the authorized project, levees were raised on the east, north, and south sides of the settling basin. The upstream limit of the work is Road 102. Because of the authorized work, only existing project levees on Cache Creek upstream of Road 102 have been evaluated in this phase of the Sacramento River Flood Control System Evaluation.

Area Description. - The study area is in California's Central Valley south of the city of Sacramento, along the lower Sacramento River and its tributaries and distributary sloughs and the Yolo Bypass. Portions of Cache Creek, Willow Slough Bypass, and Putah Creek (all north or west of Sacramento) at their confluence with the Yolo Bypass are also within the study area.

Climate in the lower Sacramento area is similar to that in the Central Valley, with warm, dry summers and moderate winters, followed by a cool, rainy season from November through April. Annual rainfall averages 15 inches per year, with most falling from December through March. Summer breezes are usually cool, and winds up to 25 miles per hour are common.

The study area is within the Sacramento Valley Air Basin. The air basin is a non-attainment area as defined by the Environmental Protection Agency. The major air pollution problems are high concentrations of oxidants, primarily from motor vehicles, and suspended particulate matter from the agriculture and lumber industries.

Sacramento River water quality is generally good, but the quality varies at specific sites due to the effects of variable streamflows and the quantity of local waste discharges and irrigation return flows. Water quality in the distributary channels of the Delta is affected by intrusion of saline seawater. This intrusion is of increasing concern as consumptive uses of fresh water continue to increase throughout the State.

Land use in the Lower Sacramento Area is predominantly agricultural (row, grain crops, and orchards). Residential and commercial development has been minor in or near Rio Vista, Isleton, Walnut Grove, Locke, Hood, Clarksburg, and Freeport. Marinas are common along the Sacramento River.

Riparian vegetation is restricted to scattered narrow bands typically less than 30 feet wide on narrow banks, berms, and levee faces along the lower Sacramento River and its tributaries and distributary sloughs. Wider and denser stands are present where levee maintenance has been neglected. Also, shaded riverine aquatic habitat type is of particular importance along the lower Sacramento River and sloughs. The only Federally listed endangered plant species that may be present in the study area is the Antioch dunes evening primrose. Federal candidate species that may be present are the Suisun marsh aster, California hibiscus, Delta tule pea, and Mason's lilaeopsis (also listed by the State of California as threatened or rare).

Wildlife on the lower Sacramento River is associated with vegetation available for food, cover, and nesting. Depending on the habitat, species such as Virginia opossum, gray fox, western gray squirrel, raccoon, ringtail, muskrat, bat, California ground squirrel, and Botta's pocket gopher may be present in the study area. The Pacific western big-eared bat may also be in the study area and is a Federal candidate species.

Bird species which may be found include owls, crows, ravens, hawks, woodpeckers, wood ducks, cormorants, herons, egrets, bitterns, red-winged blackbirds, marsh wrens, starlings, Brewer's blackbirds, ring-necked pheasants, California quail, mourning doves, Anna's hummingbird, scrub jay, blackheaded grosbeak, and house finch. Also, the Swainson's hawk, which is listed by the State as a threatened species, has been observed between Grand Island and Sacramento.

Amphibians and reptiles which may be in the study area include the Pacific tree frog and the giant garter snake. The giant garter snake is proposed for Federal listing as an endangered species and is listed by the State of California as a threatened species. The northwestern pond turtle is a Federal candidate species.

The Sacramento River supports an array of anadromous and resident fish species. Anadromous fish include four races of chinook salmon, steelhead trout, striped bass, American shad, green and white sturgeon, and Pacific lamprey. Resident species include largemouth bass, black bass, catfish, white and black crappie, warmouth, Sacramento squawfish, and Sacramento sucker. The winter-run chinook salmon and Delta smelt are on the Federal list of <u>threatened</u> species; and the Sacramento splittail, Sacramento perch, and green sturgeon are candidate species.

The valley elderberry longhorn beetle, which may also be present in the study area, is Federally listed as a <u>threatened</u> species.

No prehistoric or historic cultural resources were identified during a survey of 52 boring-hole locations within the Phase IV project area. A review of literature on file at the North Central Information Center at California State University, Sacramento, and the Northwest Information Center at Sonoma State University found no previously recorded sites within the project area. Five sites were located in the general vicinity of the project levees. Thirteen areas of potential effect were surveyed and one historic site (two railroad berms separated by Georgiana

Slough) was identified and recorded. The Corps did not evaluate the site for the National Register of Historic Places since the site would not be affected by designs.

HAZARDOUS, TOXIC, AND RADIOACTIVE WASTE (HTRW) SITES

All proposed reconstruction sites were visited. A few areas near the levee toe may require testing (such as farmyards and agricultural sheds), but no obvious toxic problems were seen. The Documentation Report for the "Sacramento-San Joaquin Delta, California, Special Study," March 1993, includes an HTRW reconnaissance assessment prepared in November 1992 by Ecology and Environment, Inc. (see Volume 4, Section G, Attachment C). Brannan-Andrus, Sherman, and Twitchell Islands were among the islands reviewed for potential HTRW contamination in Phase IV, Lower Sacramento Area. No HTRW sites were within 100 feet of the proposed Phase IV work on these three islands, except for the City of Isleton Sewage Disposal Ponds, which are within 100 feet of the levee toe along 300 feet of a proposed area of levee raising along Georgiana Slough on Brannan-Andrus Island.

Additional HTRW investigations will be done as part of the Design Memorandum and plans and specifications. All borrow, borrow sites, and project lands will need to be free of HTRW before the lands can be used for project reconstruction. Some of the potential borrow sites have already been certified as being free of HTRW. The Corps field investigations to date have provided no evidence that an HTRW problem exists within the project area.

CHAPTER III - PROBLEMS AND OPPORTUNITIES

FLOOD PROBLEMS

The lower Sacramento study area covers portions of Sacramento County (population 1,121,200), Solano County (369,500) and Yolo County (148,800). The largest cities in the area are Davis and Woodland (west and north of Sacramento in Yolo County), with populations of 50,100 and 41,850, respectively. Smaller communities include Freeport (population included in city of Sacramento); Walnut Grove (1,500), Isleton (870), Courtland (500), Hood (435), and Ryde (300), all in Sacramento County; Rio Vista (3,690) in Solano County; and Clarksburg (250) in Yolo County. Estimates are from the California Department of Finance, Population of California Cities, January 1992 and 1993; for Walnut Grove, Clarksburg, Courtland, Hood, and Ryde, estimates are from the Rand McNally 1993 Commercial Atlas and Marketing Guide.

Historic Flooding

Prior to construction of the Central Valley Project (CVP) in the 1940's, Delta flooding was characterized by frequent inundation of vast tracts of land. With the advent of the CVP, flooding was reduced to inundation of individual islands or tracts due to overtopping. Since 1950, construction of additional upstream dams has further reduced the threat of overtopping. Levee failures, now more likely to be due to levee instability, continue to be a serious problem with project and non-Federal levees. Since 1950, 19 Delta islands have been flooded and restored, some more than once, and flood fights have been waged and won on most of the remaining project and non-project levees.

On 20 January 1969, a privately owned levee on Sherman Island (RD 341) failed when a sudden massive crack enlarged within minutes to a gap 300 feet wide and 40 feet deep. Structures were flooded to depths of 4 to 5 feet and were a complete loss as a result of wind and wave action. About 200 people living on the island were affected. In addition, traffic on Highway 160, a major Delta route, was disrupted. The Corps was called in to repair the break as the tide ebbed and flooded. Total damages were estimated at $7 million (1969 dollars). This was the first of a series of levee breaks and flood fights during the first 4 months of 1969 when moderately high water levels, aggravated by driving rains and winds, caused unexpected erosion of numerous levee sections through the Delta.

Shortly after midnight on 21 June 1972, a private levee on Brannan-Andrus Island (RD 2067, RD 317, and RD 407) failed with an eventual breach of 500 feet. Both Andrus Island (RD 556) and the adjoining Brannan Island suffered flooding as an estimated 164,000 acre-feet of water flowed through the breach. The levee failed at a high tide stage of about 3.7 feet mean sea level, due to instability rather than overtopping. The city of Isleton, located across Brannan-Andrus Island opposite the levee break, was threatened. At the request of the State Office of Emergency Services, the Corps constructed a ring levee to prevent flooding of the city. An 8,000-foot-long levee was constructed to a height of 5 feet before rising floodwaters overtopped the temporary levee on 22 June, stopping all work. About 35 percent of the city of Isleton, including the sewage treatment facilities, was inundated. About 2,000 residents were evacuated because of health concerns. On 27 June, the area was declared a national disaster. The levee breach was closed 26 July, and residents were allowed to return to their homes on 15 September. Total damages were estimated at $27 million (1972 dollars).

Floods of February 1986

Major storms in February 1986 resulted in floods of record for many parts of northern and central California. Record flow releases from reservoirs impacted downstream levee systems, eroded levee embankments, and exceeded flood control project design levels.

At 3 a.m. on 19 February 1986, a non-project levee failed at two 300-foot-long sites on the Mokelumne River, causing flooding to most of Tyler Island (RD 563). The city of Walnut Grove, located on the Sacramento River at the north end of Tyler Island (RD 554), was threatened by flooding; 300 people were forced to evacuate. A Department of Water Resources (DWR) command center was set up at Walnut Grove to direct the flood fight, and up to 30 work crews from the Conservation Corps and Division of Forestry assisted. Two Forestry helicopters were used in the flood fight and removal of injured or stranded flood victims. At 5:00 a.m. on the 19th, the Corps of Engineers awarded a contract to build a 2,300-foot-long, 8-foot-high temporary levee to prevent flooding of the residential sections of Walnut Grove (see Figure 1). Fill material placed on the crown of the levee road prevented overtopping by floodwaters, at a cost of $267,000. Total flood damages to Tyler Island were approximately $10.4 million (1986 dollars).

To prevent levee failure and flooding in the city of Isleton, the Corps on 19 to 21 February placed sand material along 300 feet of non-Federal levee for Brannan-Andrus Island at a cost of $175,000. Sand was placed at a second 800-foot-long site between 22 February and 7 March, at a cost of $128,000.

C-103365

FLOODING SOUTH OF WALNUT GROVE DURING FEBRUARY 1986 FLOOD
FROM NON-PROJECT LEVEE BREAKS

FIGURE 1

C-103366

Non-project levees adjacent to Rio Vista held during the 1986 storms, but more than 20 homes were flooded by high tides. Between 11 and 15 March, the Corps placed riprap along the levee near Clarksburg (on Grand Island) to prevent further levee erosion and potential levee failure. The cost of the repair was $95,000.

It should be noted that no levee failures (i.e., breaching) have occurred along the Sacramento River or its distributary sloughs in the Lower Sacramento Area, Phase IV, on Federal levees of the Sacramento River Flood Control Project since the project was built. Levees have failed on Cache Creek in the study area, however.

CHAPTER IV - TECHNICAL STUDIES

This chapter presents a detailed discussion of the technical studies of the investigation. Data are provided on historic levee embankment problem areas, levee crown surveys, and high-water marks of the February 1986 flood, as well as hydrologic studies addressing the evaluation of stage-frequency data and the analysis of the 1986 high-water mark and design water-surface profiles. The geotechnical studies include a detailed evaluation of the slope stability of the levees and the potential for levee failure due to seepage and piping. This chapter also covers economic studies, including the analyses of potential flood damages.

FIELD DATA

Historic Levee Embankment Problem Areas

To determine past problem areas, Department of Water Resources personnel interviewed individuals responsible for maintaining the levees within the study area. DWR personnel also accompanied knowledgeable individuals from the maintaining agencies on levee inspections to locate and identify areas of concern. Particular emphasis was given to identifying the levee embankment problem areas that resulted from the February 1986 flood, including high water, bank erosion, seepage, and boils.

Prior to commencing the field drilling explorations for the geotechnical programs, personnel from the geotechnical consulting firm Harlan Tait Associates, under contract to the Corps, performed a reconnaissance of the subject levees. The reconnaissance was completed in April 1990 ("Report on Recommendations for Explorations, Further Study, and Laboratory Testing," Harlan Tait Associates, April 1990) and consisted of field inspections of potential and existing levee embankment problem areas. During their field investigations, the existing condition of the levees was observed, near-surface soil conditions were determined by probing, and future exploration locations were selected.

Historic levee embankment problem areas, including type of problem and general location, are noted on Plate 3, particularly problems that resulted from the February 1986 flood. In addition, some of the problems are described below:

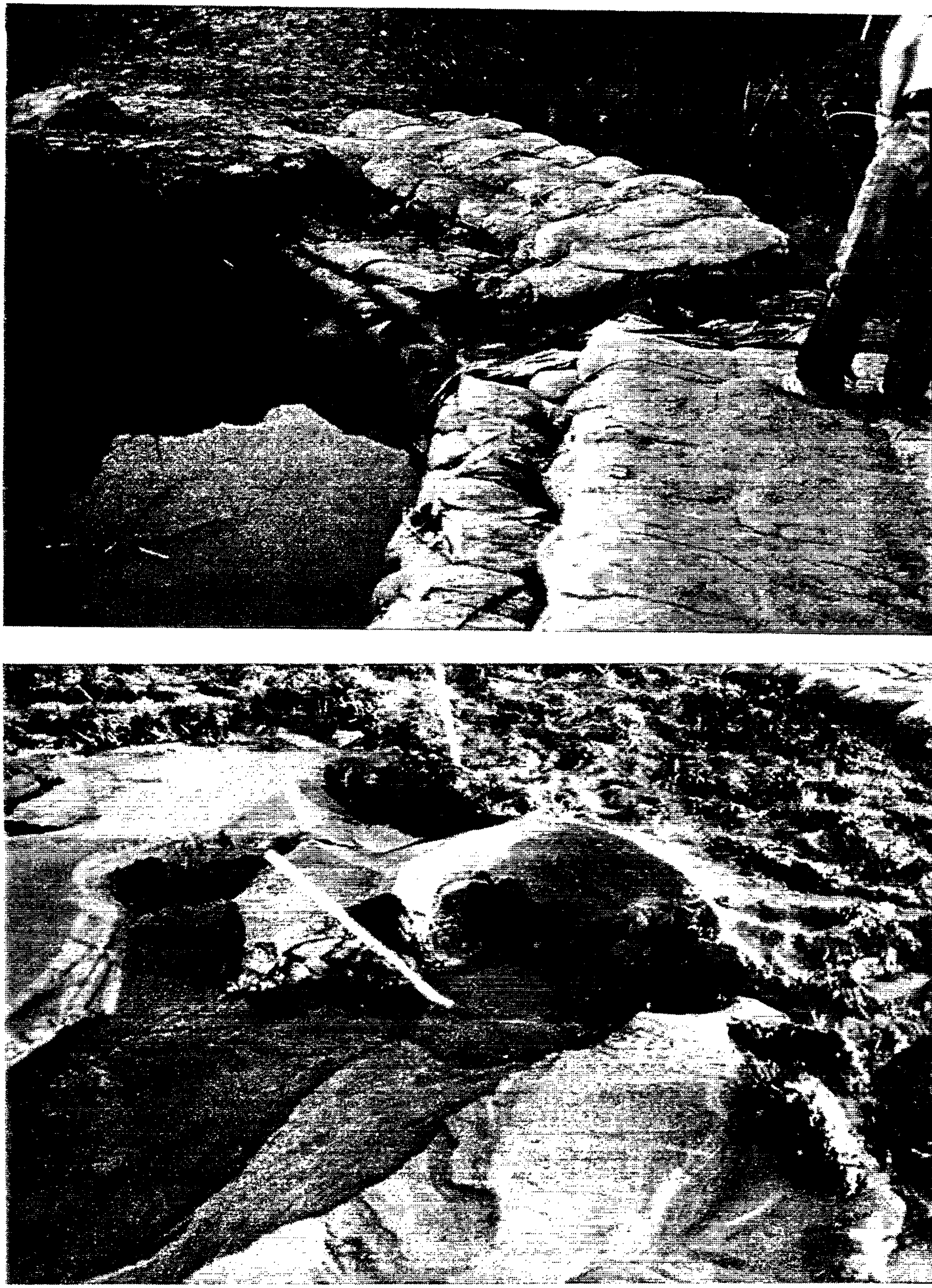
Sacramento River. - Boils and seepage areas (as noted on Plate 3) have occurred at the landward toe and landward of both levees of the Sacramento River during high flows. During the February 1986 flood, boils were sandbagged by local agencies and the California Conservation Corps in Reclamation Districts 3, 150, 556, and 755, as shown on the front cover and Figures 2 and 3. The sandbagged boils shown on Figures 2 and 3 discharged significant amounts of sandy material. In addition, a sinkhole was observed in the vicinity of the boil shown in Figure 3. Several boils were sandbagged to heights ranging from 4 feet to 6 feet (see front cover). There is also a seepage area about 3 miles long adjacent to the levee embankment near the southern limit of Reclamation District 3. At the lower limit of the project levee system, landside levee embankment slope failures are a continual problem. The slope failures result in levee crown and embankment subsidence (see Figure 4), flatter landside levee slopes, and a broader levee embankment base. The county road was moved from the levee crown in this area several years ago to avoid the continual road maintenance associated with these slope failures. Some of the slope failure repairs have included a landside berm about 50 feet wide at the landward toe of the levee to minimize the potential for future slope failures.

<u>Georgiana Slough</u>. - Seepage areas are visible on the land surface adjacent to both levees in the lower reach of Georgiana Slough (see Plate 3). Even during normal flows, seepage waters are sufficient to support tule-growth near the landward toe of the levee.

<u>Threemile Slough</u>. - Seepage is significant along 2 miles of levee on both sides of Threemile Slough upstream of the San Joaquin River. In some areas, the adjacent lands are wet all year, precluding agricultural operations, and support wetlands vegetation. In some areas, seepage appears on the lower slope of the levee during normal flow (see the lower photograph of Figure 5). In the early 1980's, a toe berm about 100 feet wide was added to the east levee of Threemile Slough (RD 1601) when the Corps of Engineers used this area as a disposal site for dredged material. Significant seepage waters are still observed in this area even with the toe berm.

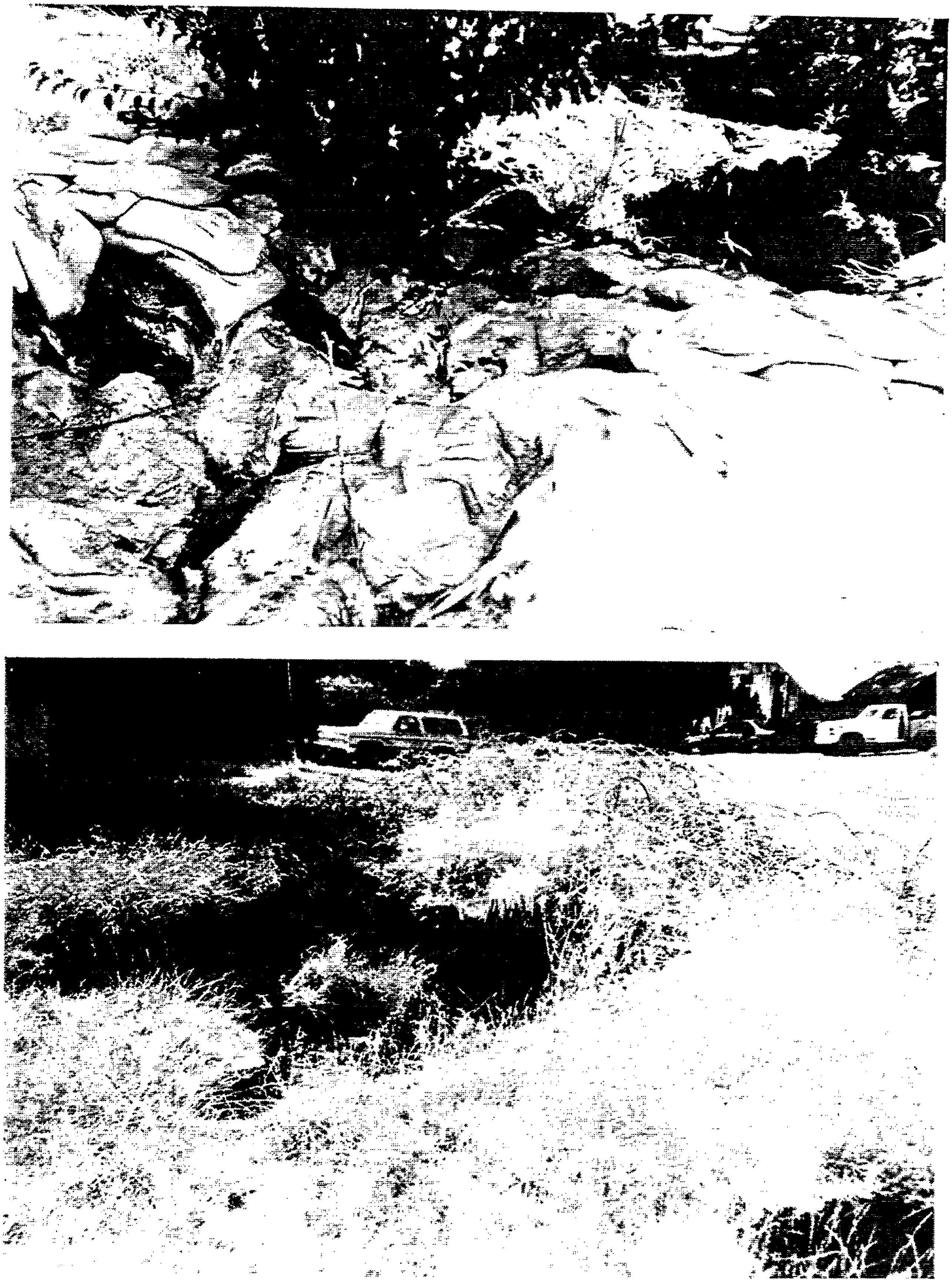
<u>Steamboat Slough</u>. - During the high flood stages of 1986, the California Conservation Corps reportedly sandbagged six boils. Several of the boils were observed transporting significant amounts of sand (see the lower photograph of Figure 6). In addition, seepage occurs on both sides of Steamboat Slough, particularly in Reclamation District 3, and in some areas occurs even during normal flow conditions (see the upper photograph of Figure 5). Local landowners have constructed drains and ditches at several seepage sites (Figure 5) to minimize potential problems.

<u>Yolo Bypass</u>. - Significant seepage areas occur along the east levee of Yolo Bypass during flood periods (see Plate 3).



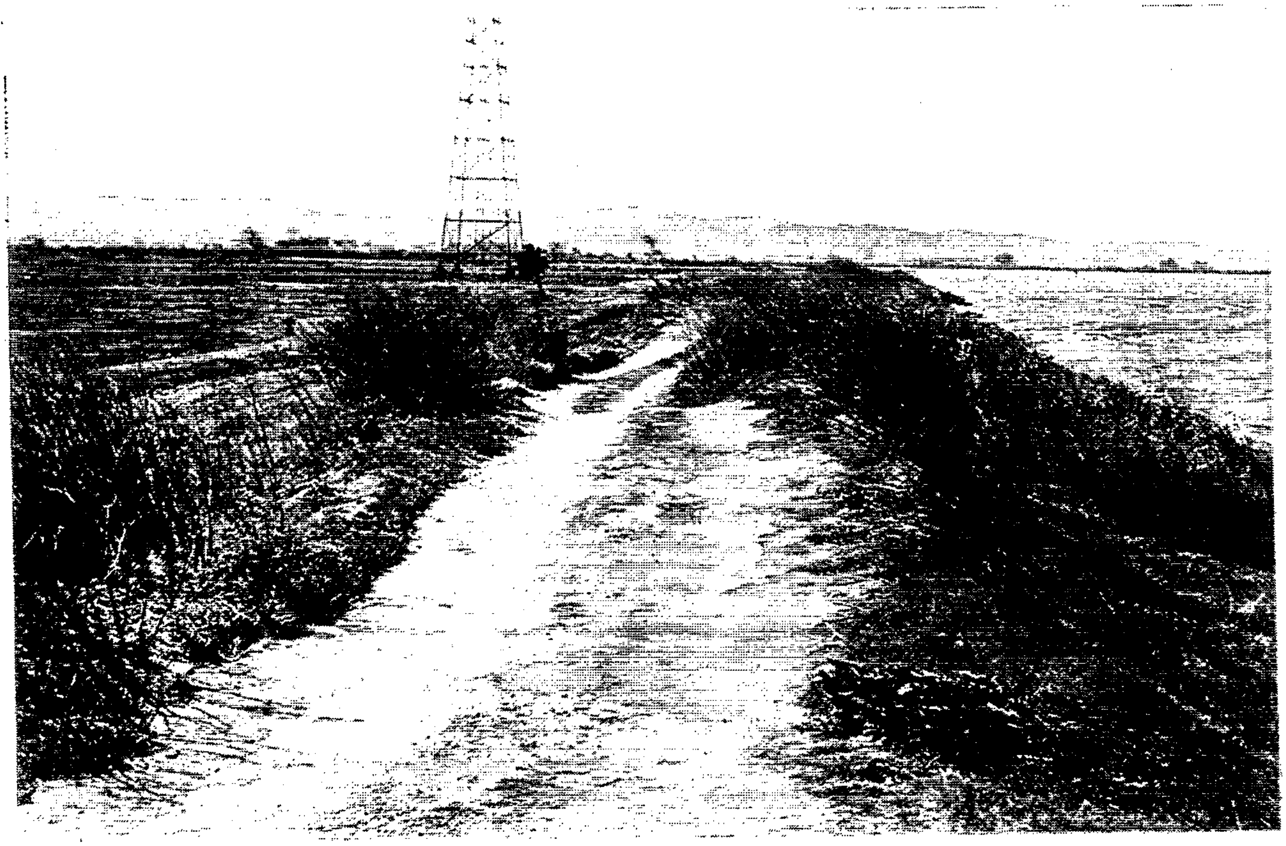
SANDBAGGING OF BOILS DURING FEBRUARY 1986 FLOOD NEAR SACRAMENTO RIVER PROJECT LEVEE IN R.D. 556

FIGURE 2



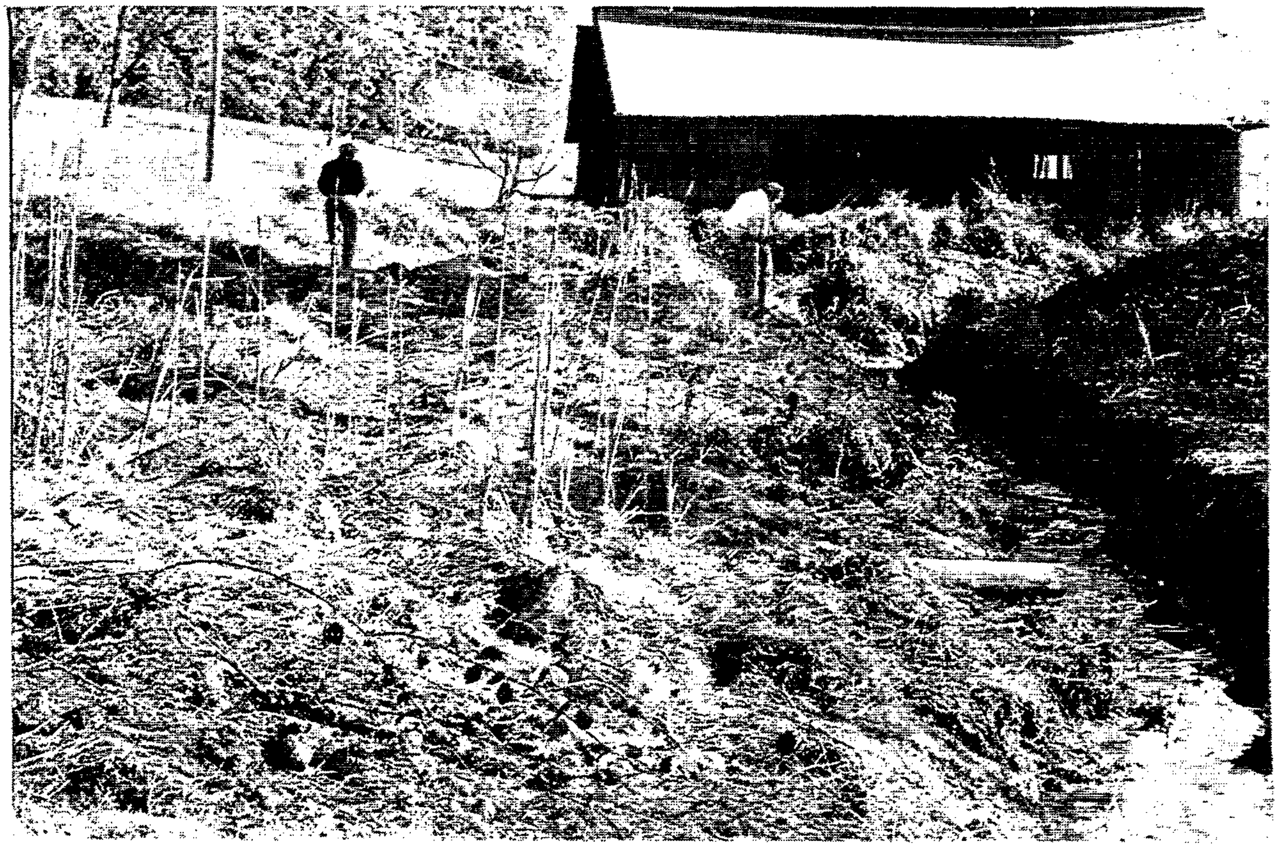
BOIL AND SINKHOLE RESULTING FROM FEBRUARY 1986 FLOOD NEAR SACRAMENTO RIVER PROJECT LEVEE IN R.D. 150

FIGURE 3



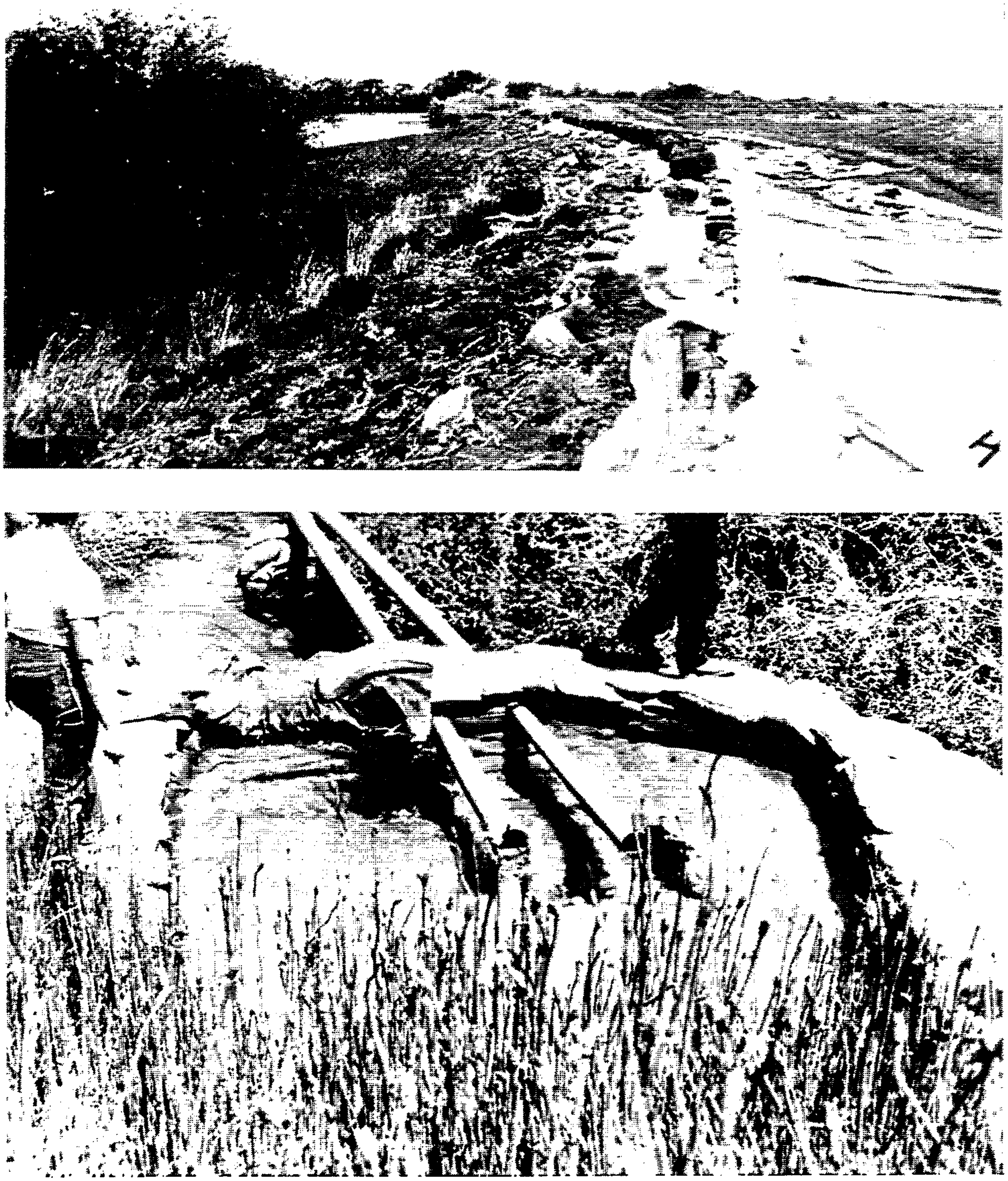
LEVEE EMBANKMENT SUBSIDENCE
SACRAMENTO RIVER PROJECT LEVEE IN R.D. 341

FIGURE 4



SEEPAGE WATERS VISIBLE ON LANDWARD SIDE OF LEVEE
DURING NORMAL RIVER FLOWS

FIGURE 5



EMERGENCY FLOOD FIGHT EFFORTS IMPLEMENTED DURING FEBRUARY 1986 FLOOD.
UPPER - FLOOD STAGES WERE WITHIN 1 FOOT OF LEVEE CREST, CACHE SLOUGH.
LOWER - BOIL TRANSPORTING SAND, STEAMBOAT SLOUGH.

FIGURE 6

Levee Crown Surveys

Levee crown surveys were conducted in October and November 1989 on Cache Creek, Willow Slough Bypass, and Putah Creek and between May and August 1990 for the rest of the Phase IV, Lower Sacramento Area by DWR personnel in conjunction with the Corps. Levee crown elevations are referenced to mean sea level datum. Levee crown stationing (and the design water-surface profile) was based on "Levee and Channel Profiles," Corps of Engineers, March 1957.

Survey points were taken on the centerline of the levee crown every 500 feet and at breaks in the levee crown profile. Additional survey points were taken at railroad crossings, road crossings, powerline crossings, Corps drill sites, and at other significant physical features. Levee crown profiles developed from the survey data are shown on Plates 5 through 19.

The profile plots indicate the nonuniformity in the levee crown surfaces in the study area. In addition, the plots indicate that some railroad and road crossings cut through the levee embankments at elevations 1 to 3 feet below the adjacent levee crown elevations.

Cross-Section Surveys

DWR personnel also provided cross-section surveys of the levee embankment at exploratory drill hole locations and at 1,000-foot intervals for specific levee reaches (surveyed cross sections referenced to mean sea level datum). The cross sections define the levee embankment above the adjacent land surface and include landside and waterside ditches that are close to the toe of the levee (within about 200 feet).

The cross sections were used primarily in potential designs for raising the levee in those reaches that do not have the minimum freeboard requirements specified for the Sacramento River Flood Control Project. (See Table 2 and "Levee and Channel Profiles," Corps of Engineers, March 1957.) In addition, the existing cross sections were compared to the Corps cross sections used in the original design and construction of the project levees. In general, the original designs specified a 20-foot crown width for the bypass and major streams and a 12-foot crown width for minor streams. Bypass levee embankment slopes specified range from 2-1/2 to 4:1 (2-1/2 to 4 horizontal on 1 vertical) on the waterward side and 2-1/2:1 on the landward side. Flatter bypass levee slopes were required in some areas because of the potential for wave erosion. Major and minor streams were originally designed with 3:1 waterside slopes and 2:1 landslide slopes.

TABLE 2

LEVEE EMBANKMENT DESIGN FREEBOARD
LOWER SACRAMENTO AREA

Location	Design Freeboard [1] (feet)
Cache Creek	3
Willow Slough Bypass	3
Putah Creek	3
Sacramento River	3
Yolo Bypass	6
Elk Slough	3
Sutter Slough	3
Georgiana Slough	3
Steamboat Slough	3
Miner Slough	3
Haas Slough	3
Cache Slough	3
Ulatis Creek	3
Lindsey Slough	3
Threemile Slough	3

[1] Minimum freeboard required in the specified reaches of the project levee system.

The comparison indicated that particular locations have less than the design crown width and that levee embankment slopes are flatter than required in design specifications. In some cases, the differences are significant and suggest levee embankment subsidence and slumping or spreading at the base of the levee.

The contractor for the geotechnical work also provided graphical displays of the levee embankment cross section at various sites. The levee sections were used in levee stability and seepage analyses.

DESIGN WATER-SURFACE PROFILE

Design water-surface profiles were developed for each levee reach of the Sacramento River Flood Control Project, as indicated by "Levee and Channel Profiles," Corps of Engineers, March 1957. Design water-surface elevations were based on a specified design discharge (no recurrence interval or frequency was attached to that design discharge) and adopted concurrent conditions at the confluences of study area streams.

Project design flood planes were originally adopted by the March 1917 Flood Control Act as taken from House Document No. 81, 1st Session, dated 1910. In 1923, corrections were made to House Document No. 81 where recomputation indicated changes should be made. In addition, changes were made to the recommended project because of significant increases in costs, local desires, and in an effort to utilize work which had already been done by locals in the interim. Revised values for project design flows and flood planes were established and included in the report "Flood Control in the Sacramento and San Joaquin Basins," printed as Senate Document No. 23, 69th Congress, 1st Session, 1926. This is the basic document authorizing the 1928 revision of the project. Since 1928, project design flows and water-surface profiles have been reevaluated and modified based on available hydrologic information, more detailed hydraulic studies, and as various segments of the project were constructed. These revisions have been agreed to by The Reclamation Board, State of California, and the Corps of Engineers and published as "Levee and Channel Profiles, Sacramento River Flood Control Project," dated 15 March 1957.

The agreed-to 1957 design water-surface profiles are shown on Plates 5 through 19 and can be compared to the levee crown profile plots. As shown in Table 2, 6 feet is the minimum freeboard required on the Yolo Bypass, and 3 feet is the minimum freeboard on all other study area reaches to meet design requirements for the flood control project levees. An inspection of the profile plots indicates that there is <u>not</u> adequate freeboard on Cache Creek between channel miles 5 and 10, both banks; on Willow Slough Bypass between channel miles 3 and 7, both banks; and on Putah Creek at various locations between channel miles 4 and 9, both banks.

The Sacramento River levees have very localized areas of inadequate design freeboard in the vicinity of channel miles 4, 7, 38, and 45. The west levee (right bank levee) of Yolo Bypass also has inadequate design freeboard between channel miles 18 and 30. The project levee shown as the left bank levee of Yolo Bypass on Plate 9 has reaches of inadequate design freeboard, but this study levee reach no longer functions as the east levee of Yolo Bypass (see Plate 2). The east levee of Yolo Bypass in this area is now the west levee of the Sacramento River Deep Water Ship Channel.

Construction of the ship channel was completed in 1963. Soil material excavated for the channel was used in the construction of a new levee for the east side of the bypass. This ship channel levee, which now functions as the east levee of Yolo Bypass, is maintained by the Corps of Engineers and has not exhibited any significant structural problems or freeboard deficiencies to date which would warrant further geotechnical studies or potential reconstruction. In addition, significant portions of the levees on Georgiana Slough, Miner Slough, Cache Slough, Haas Slough, Lindsey Slough, and Threemile Slough have inadequate design freeboard.

The most significant design freeboard deficiency appears to be on Cache Creek (see Plate 5). A comparison of the design water-surface profile and the levee crown profiles indicates about 4 miles of levee embankment on both the left and right banks does not have as the minimum the 3 feet of design freeboard authorized. Most of the Cache Creek study reach has little or none of the design freeboard specified based on the 1989 DWR surveys. The geotechnical report, "Geotechnical Assessments of Levees in the Mid-Valley Area, Sacramento River Flood Control System Evaluation," Roger Foott Associates, Inc., December 1989, indicates stable foundation soils on Cache Creek and only a few levee embankment problem areas. In addition, the report cites no evidence of active surface faulting.

The U.S. Geological Survey in its report, "Late Cenozoic Tectonism of the Sacramento Valley, California," 1987, indicates the potential for displacement along the Zamora Fault in the area of Cache Creek, Willow Slough Bypass, and Putah Creek. Seismic activity is also possible in the area of Cache Creek upstream of Woodland as suggested in the report, "Landslide and Flood Potential Along Cache Creek," Division of Mines and Geology, May 1990. Whether regional subsidence has occurred in this part of the study area as a result of fault movement is beyond the scope of this investigation; however, data collected by the U.S. Geological Survey and California Department of Water Resources show ground-water pumping is responsible for subsidence in nearby areas to Cache Creek, and the region has problems with bench marks becoming inconsistent in elevation with time. Bench marks in this area are being resurveyed, and it may be necessary for DWR to resurvey Cache Creek to verify levee crown elevations.

Although railroad and road crossings do not meet minimum design freeboard requirements, local levee maintaining agencies should have operational procedures for sandbagging or for installing flood gates at these locations during high flood stages.

FEBRUARY 1986 HIGH-WATER MARK DATA

During and immediately following the February 1986 flood, personnel from the DWR staked high-water marks along the west levee embankment of the Sacramento River Deep Water Ship Channel downstream of West Sacramento. The high-water marks were surveyed by DWR personnel and referenced to the mean sea level datum. Similarly, the Corps of Engineers staked and surveyed high-water marks along Sutter, Georgiana, Steamboat, Miner, and Threemile Sloughs. In addition, gaged data from Table 3 were also used for the study area, and other high-water mark observations were obtained from various State and local entities.

Based on the above information, high-water mark data of the February 1986 flood were plotted for the study area levee reaches, as shown on Plates 5 through 19. The high-water mark data include the streamflow data from gages operated by the U.S. Geological Survey and DWR. The gaged data (because of the types of devices used, such as pressure manometers, stilling wells, etc.) generally represent a water-surface elevation that would be consistent with a static water surface or a static water surface plus wind setup. The gage devices essentially dampen out any wave action that might be occurring on the water surface. High-water mark stakes were generally placed where a debris line was evident on the levee embankment slopes (see Figure 7). In river reaches where wave action is not significant, the debris line elevations are probably similar to water-surface elevations observed at the gaging stations. Where larger expanses of floodwaters exist (such as Yolo Bypass) or where the wind direction generally coincides with the stream channel, wave action can be significant and can create a debris line that is significantly higher than the observed gaging station elevations. The Yolo Bypass near Lisbon gage reading (near the abandoned Sacramento Northern Railroad location) is lower than the adjacent upstream and downstream high-water marks determined from debris lines (see Plate 9, about channel mile 35). This difference can probably be attributed to wave action and will be considered when making design recommendations for modifications of levee embankments on Yolo Bypass.

TABLE 3

PEAK FLOWS AND STAGES
FEBRUARY 1986 FLOOD

Location	Time (date/hours)	Elevation (msl)	Flow (cfs)
Cache Creek at Yolo	Feb 17/2245	80.36	26,100
Putah Creek near Winters	Feb 20/1545	NA	6,630
South Fork Putah Creek near Davis	Feb 20/1745	41.96	
Sacramento River at Freeport	Feb 19/1900	25.11	117,000
Sacramento River at Hood	Feb 20/1300	20.47	
Sacramento River at Snodgrass Slough	Feb 20/1245	20.04	
Sacramento River at Walnut Grove	Feb 20/1315	14.69	
Sacramento River at Rio Vista Bridge	Feb 21/1230	8.54	
Yolo Bypass near Lisbon	Feb 20/1330	24.88	495,000 to 509,000 (estimated)
Yolo Bypass at RD 2068	Feb 20/1500	17.7[1]	
Sacramento River Deep Water Ship Channel at Ryer Island	Feb 20/1500	14.23	
Georgiana Slough at Mokelumne River	Feb 21/1545	6.96	
Threemile Slough at San Joaquin River	Feb 21/1415	6.40	

[1] Surveyed high-water mark at RD 2068 gaging location.

Since surveyed high-water marks are available only for the east levee of Yolo Bypass, those marks may not be representative of debris lines (see Figure 7) on the west levee of the bypass. The impact of wave action on debris lines would be different for the east and west levee embankments. The width and alignment of the bypass and wave action had to be considered when applying the high-water marks (debris lines) for the east levee to the west levee.

FIGURE 7

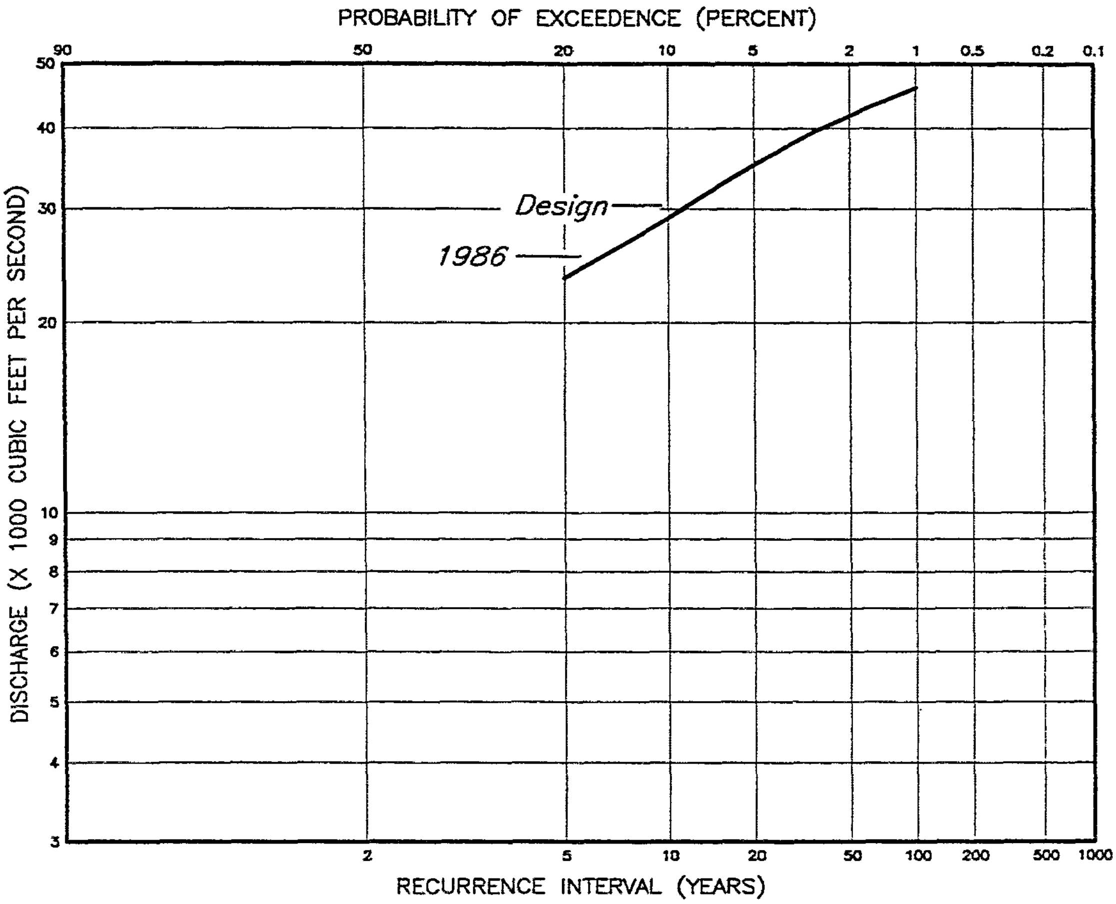
HIGH WATER MARK STAKING OF FEBRUARY 1986 FLOOD
(EAST LEVEE OF YOLO BYPASS)

A comparison of the February 1986 high-water marks and the design water-surface profiles indicates that flood stages were about equal to or exceeded designs on Willow Slough Bypass between channel miles 0 and 4, Sacramento River, Yolo Bypass, Sutter Slough, Georgiana Slough, Steamboat Slough, Miner Slough, and Cache Slough. In other levee reaches of the study area, the 1986 high-water marks were 1 to 12 feet below the corresponding design water-surface profiles.

HYDROLOGY

Discharge and stage-frequency relationships developed for the study area (Figures 8 through 32) provide information on the recurrence interval associated with the February 1986 high-water marks. Figures 8 through 32 show the 1986 peak flow or stage (see Table 3 also) and design stages at the following locations:

- Cache Creek at Yolo
- Sacramento River at I Street
- Sacramento River at Freeport
- Sacramento River at Elk Slough
- Sacramento River at Snodgrass Slough
- Sacramento River at Sutter Slough
- Sacramento River at Steamboat Slough
- Sacramento River at Walnut Grove
- Sacramento River at Rio Vista
- Sacramento River at Threemile Slough
- Sacramento River at Collinsville
- Yolo Bypass near Lisbon
- Yolo Bypass at RD 2068 Pump Station
- Yolo Bypass at Cache Slough
- Yolo Bypass at Lindsey Slough
- Miner Slough at Cache Slough
- Steamboat Slough at Cache Slough
- Georgiana Slough at Mokelumne River
- Threemile Slough at San Joaquin River
- Haas Slough at Bunker Station Road
- Ulatis Creek at Cache Slough
- Haas Slough at Sutter Slough
- Elk Slough at Miner Slough
- Sutter Slough at Miner Slough
- Sutter Slough at Steamboat Slough

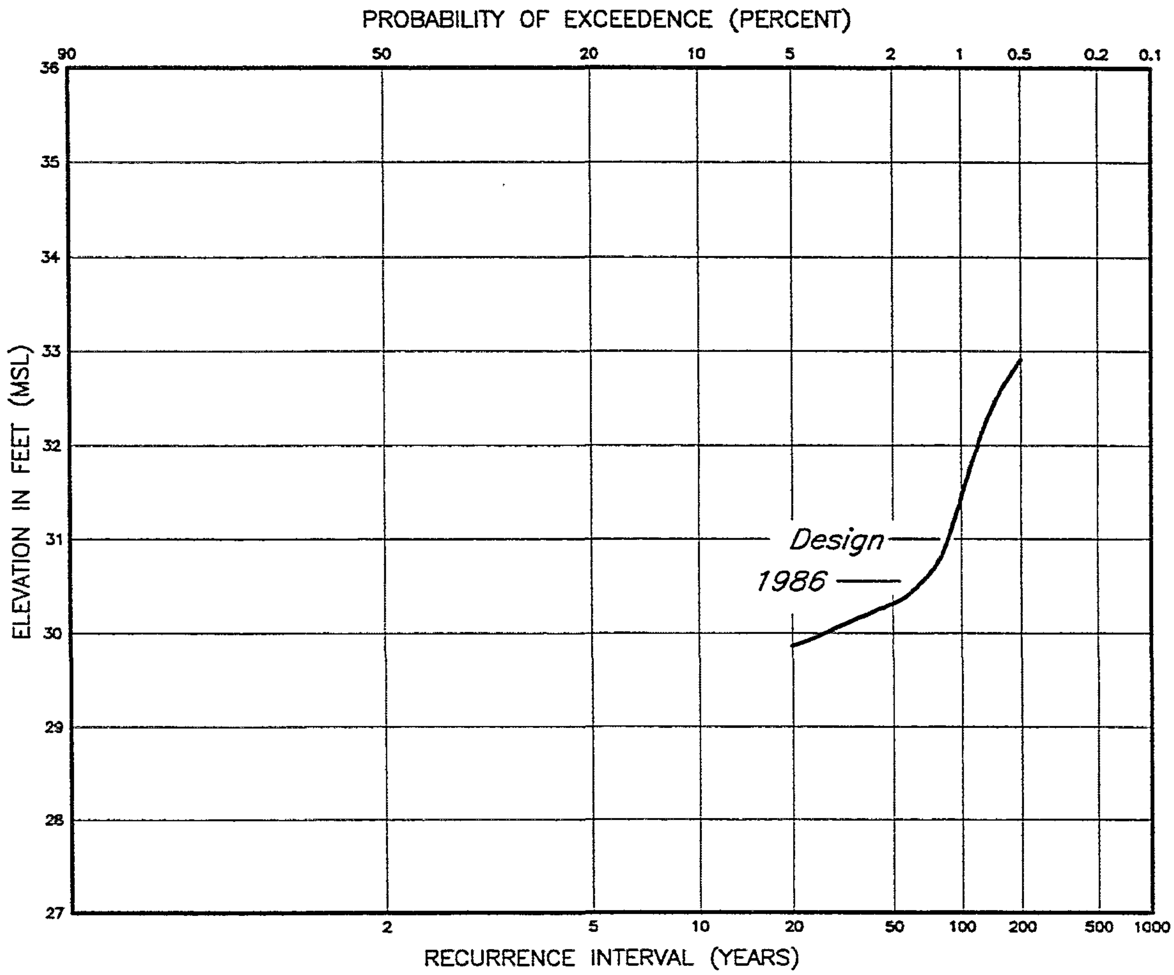


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

DISCHARGE–FREQUENCY CURVE
CACHE CREEK AT YOLO

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 8

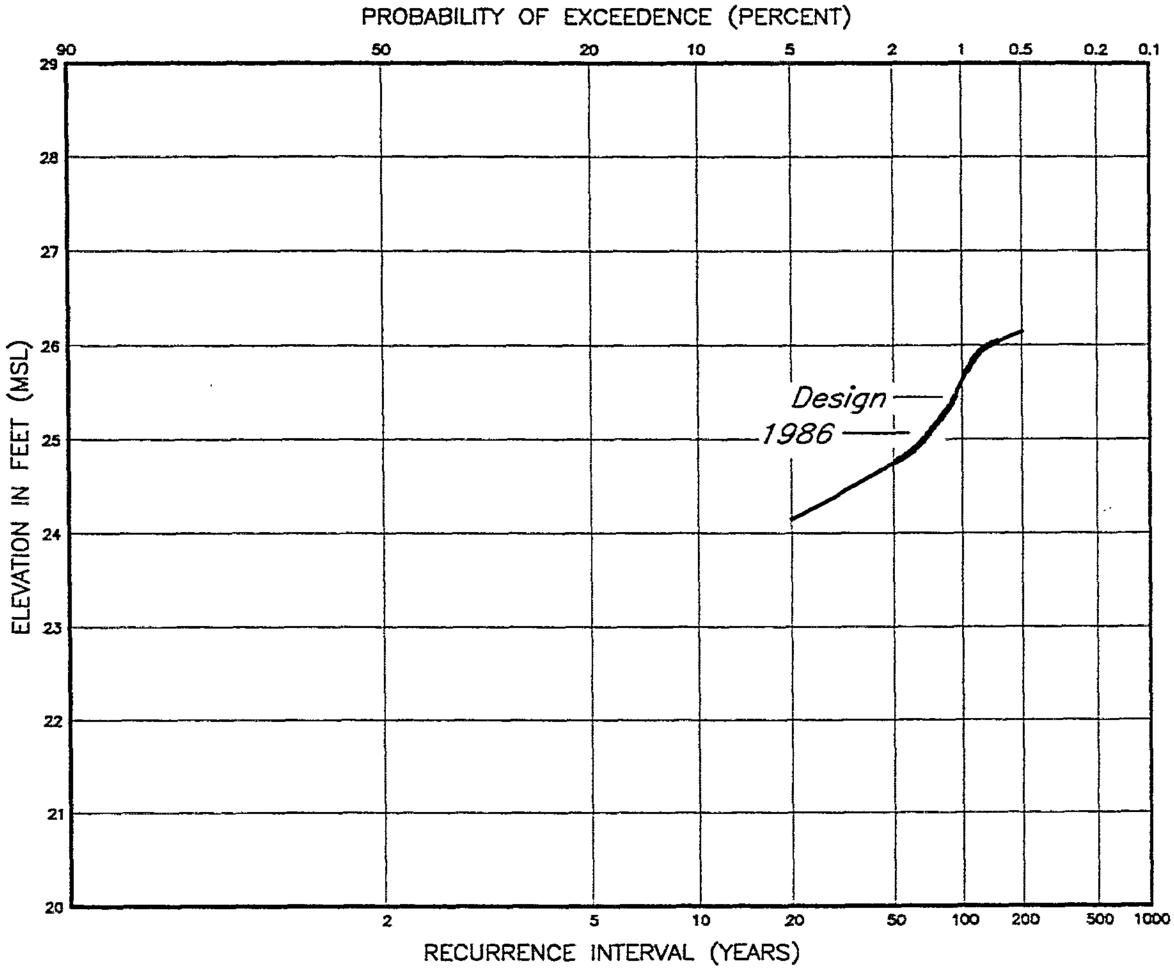


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE SACRAMENTO RIVER AT I-STREET

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 9

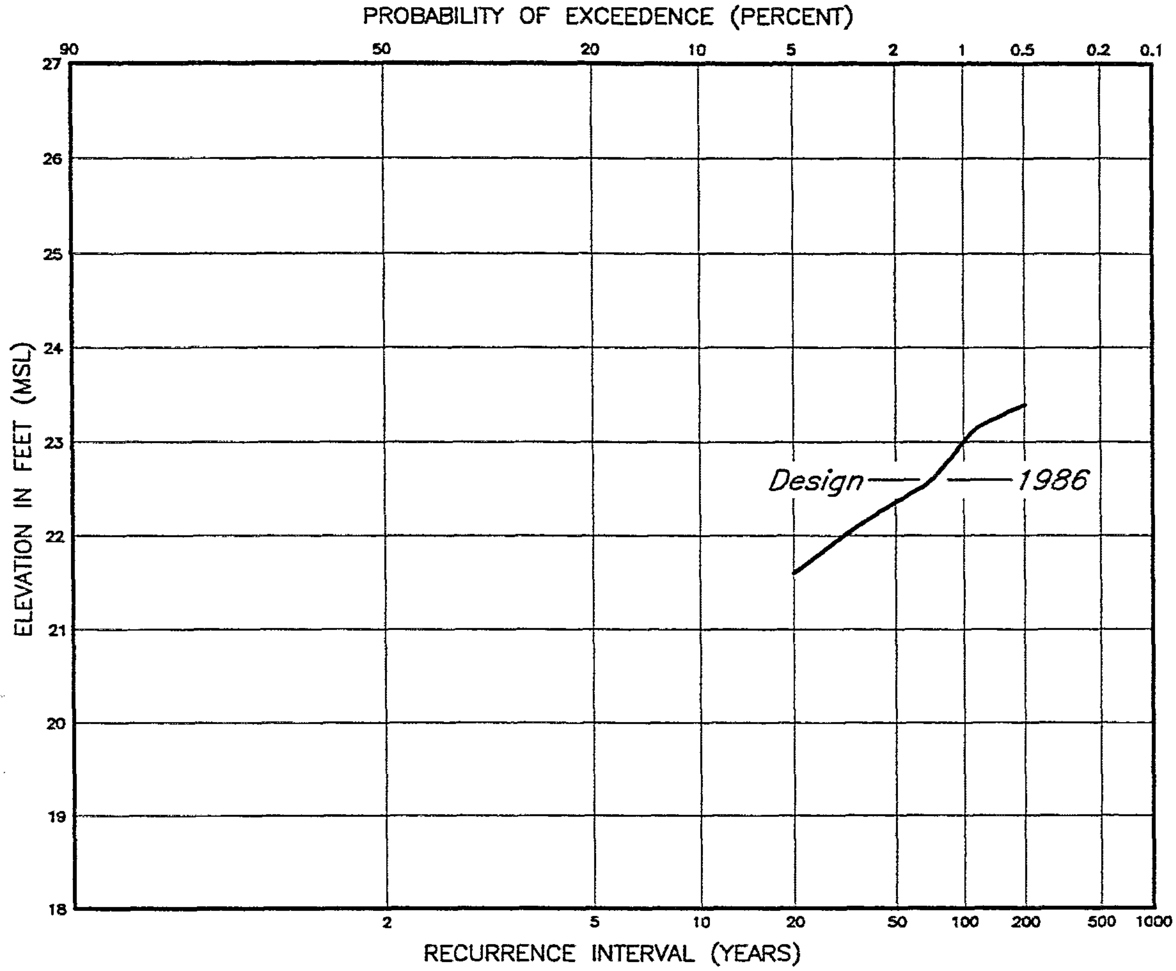


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
SACRAMENTO RIVER
AT FREEPORT**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 10

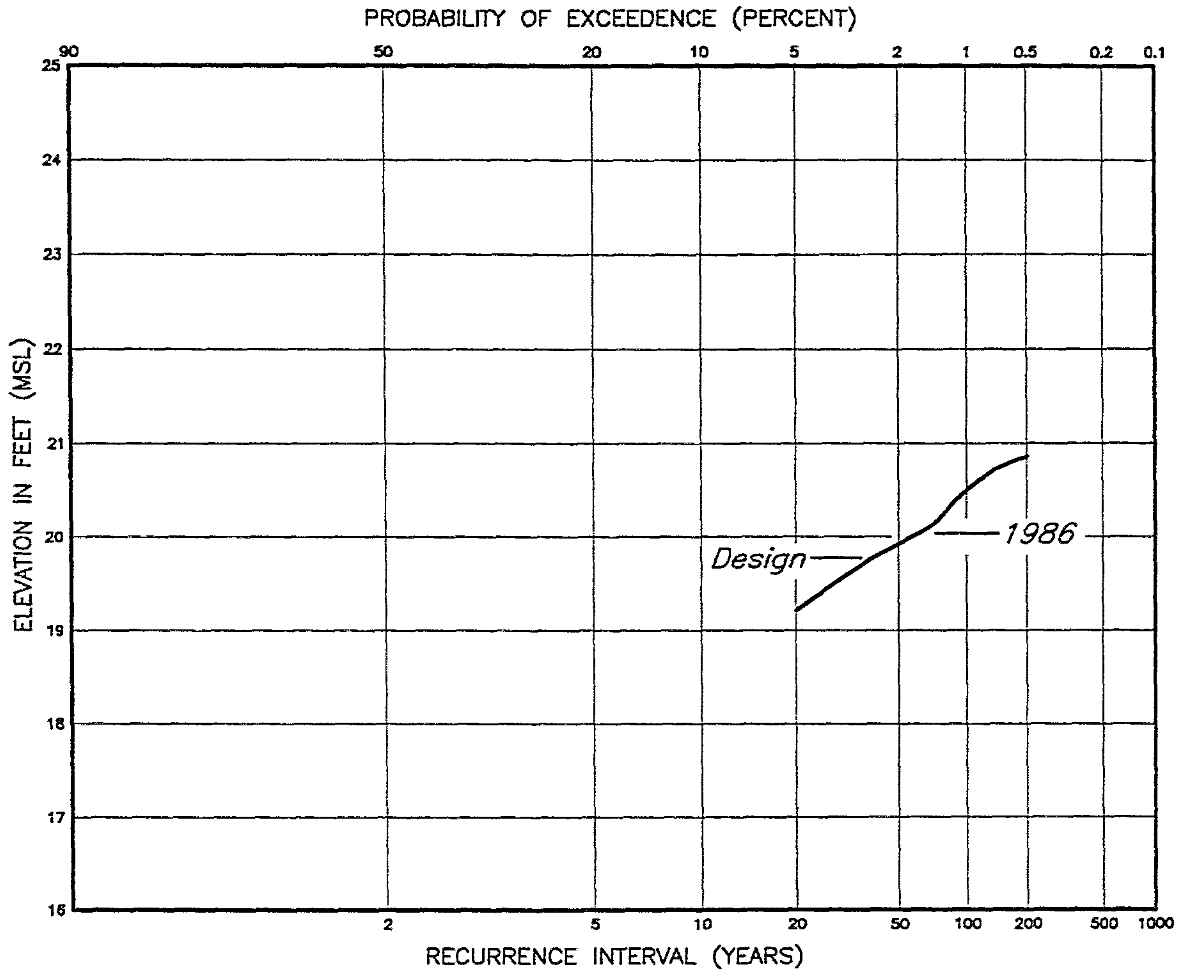


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
SACRAMENTO RIVER
AT ELK SLOUGH**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 11



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
SACRAMENTO RIVER
AT SNODGRASS SLOUGH**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
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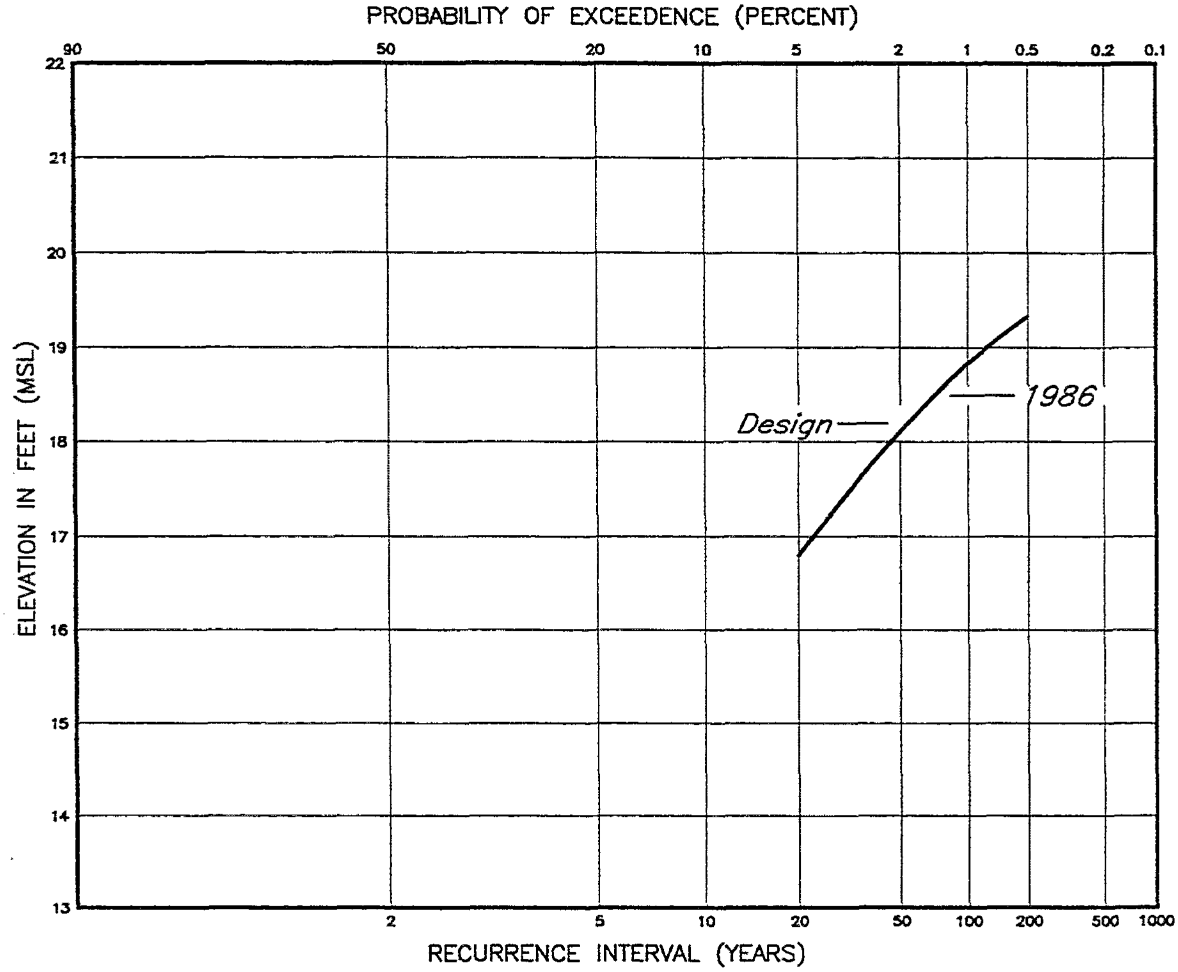
FIGURE 12

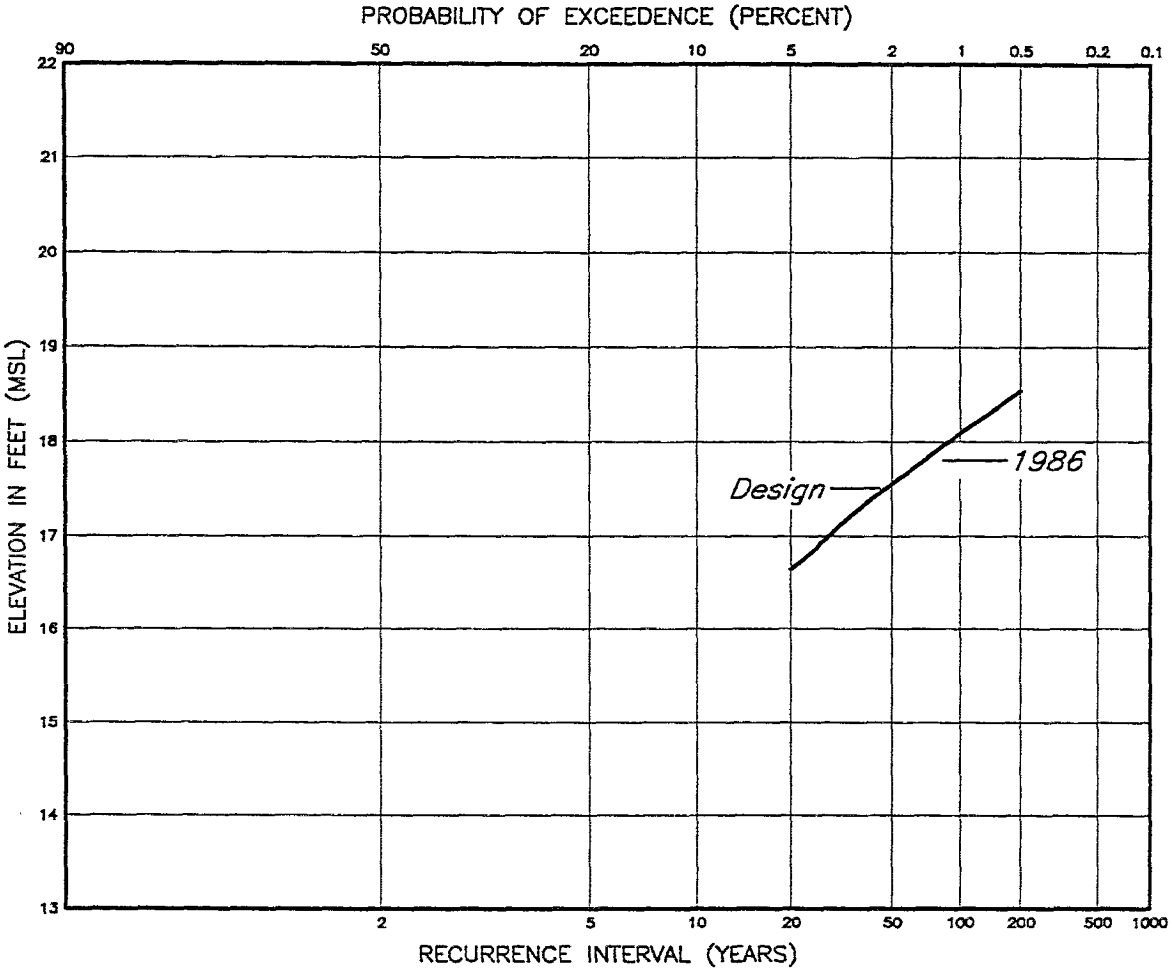


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
SACRAMENTO RIVER
AT SUTTER SLOUGH**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 13

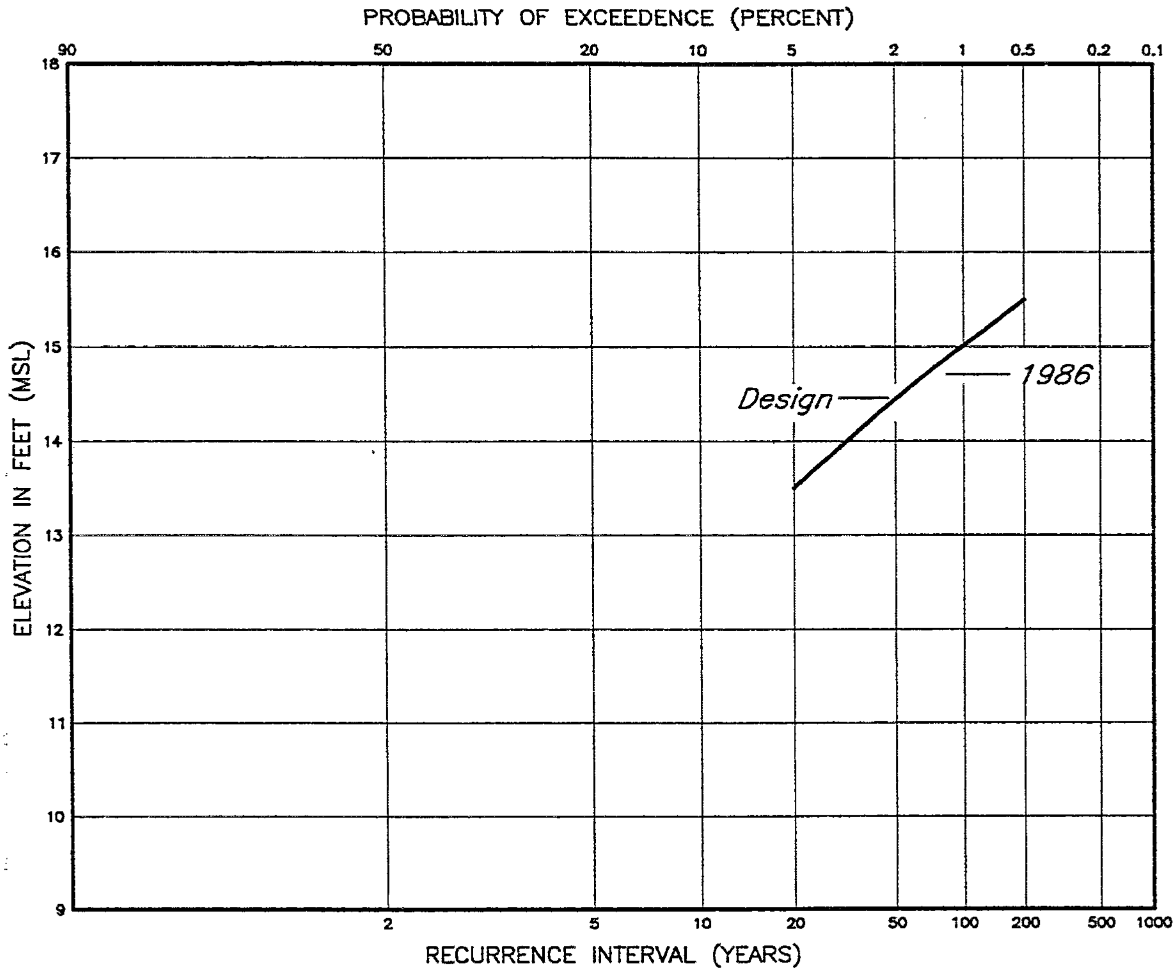


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE
SACRAMENTO RIVER
AT STEAMBOAT SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 14

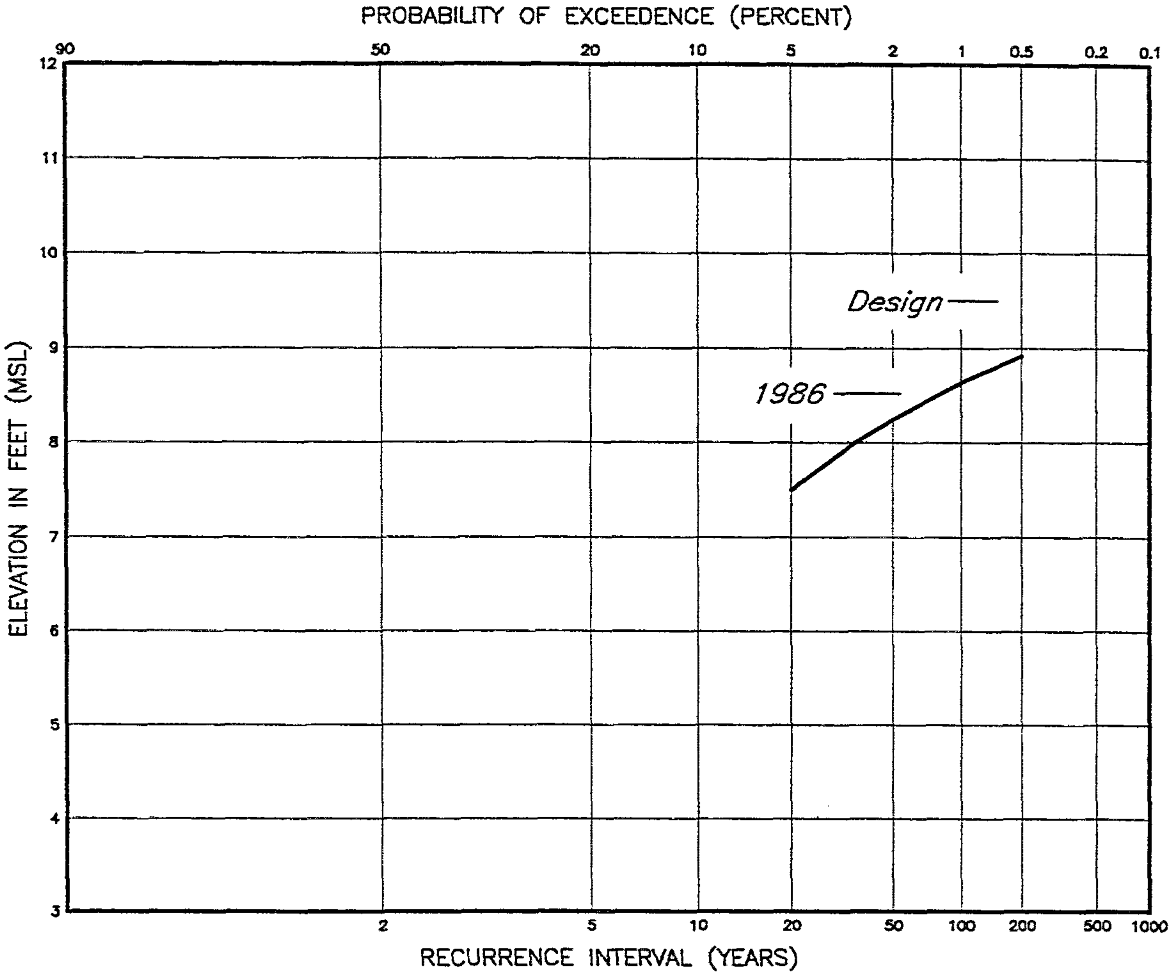


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE
SACRAMENTO RIVER
AT WALNUT GROVE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 15

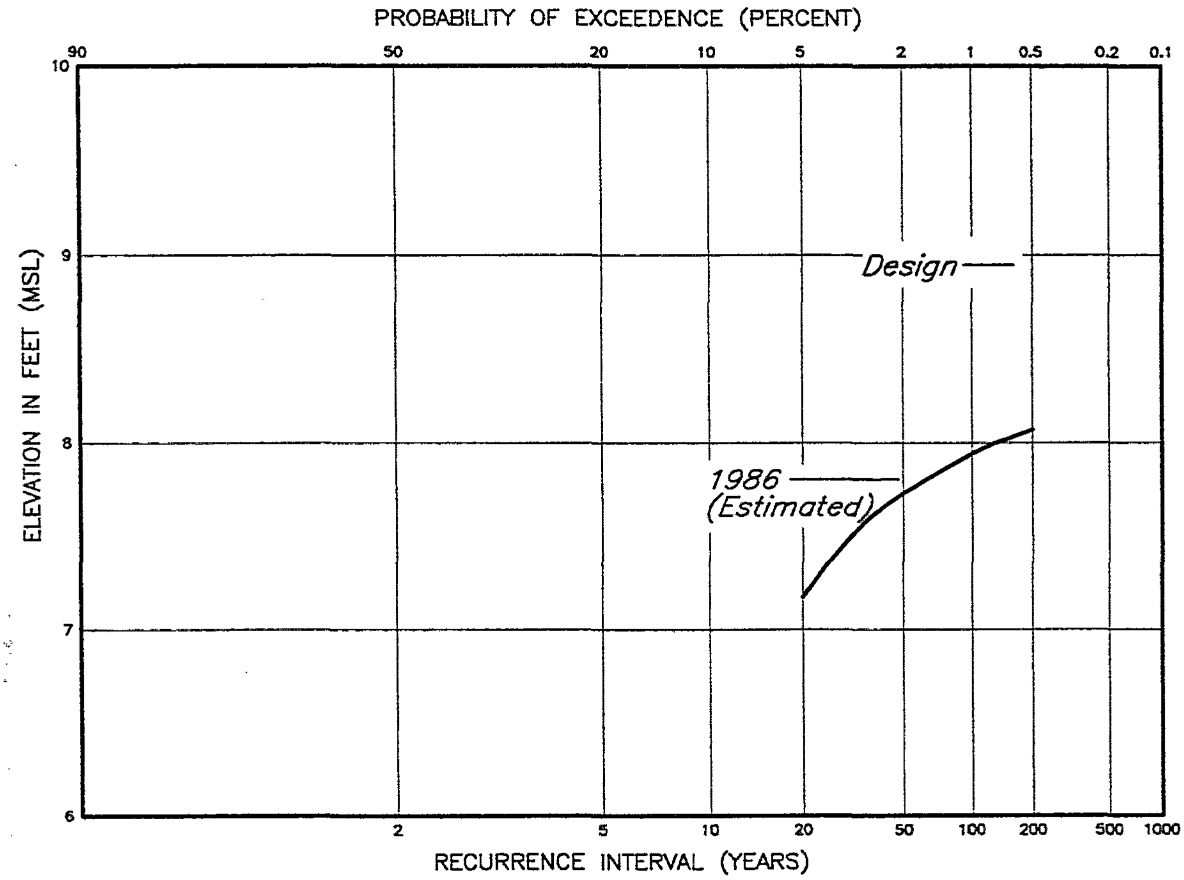


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
SACRAMENTO RIVER
AT RIO VISTA**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 16

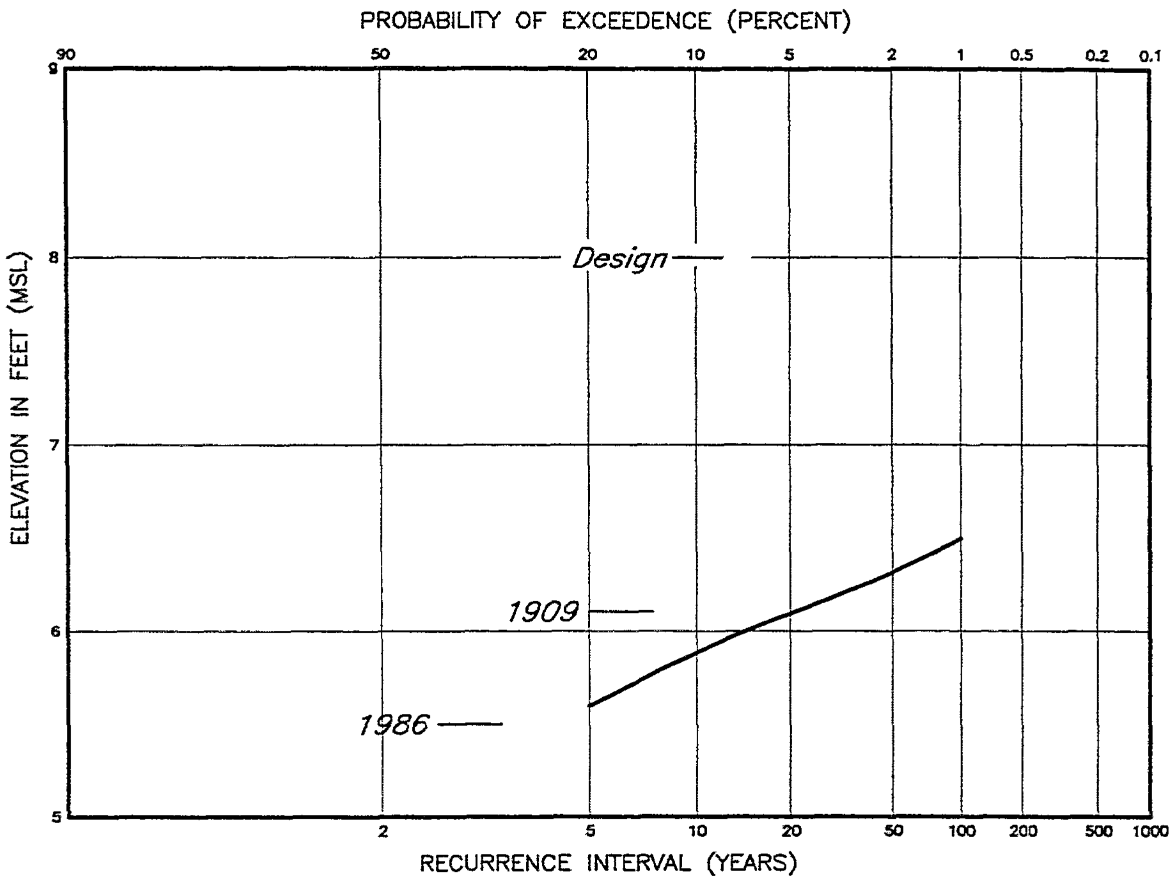


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE
SACRAMENTO RIVER
AT THREEMILE SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 17

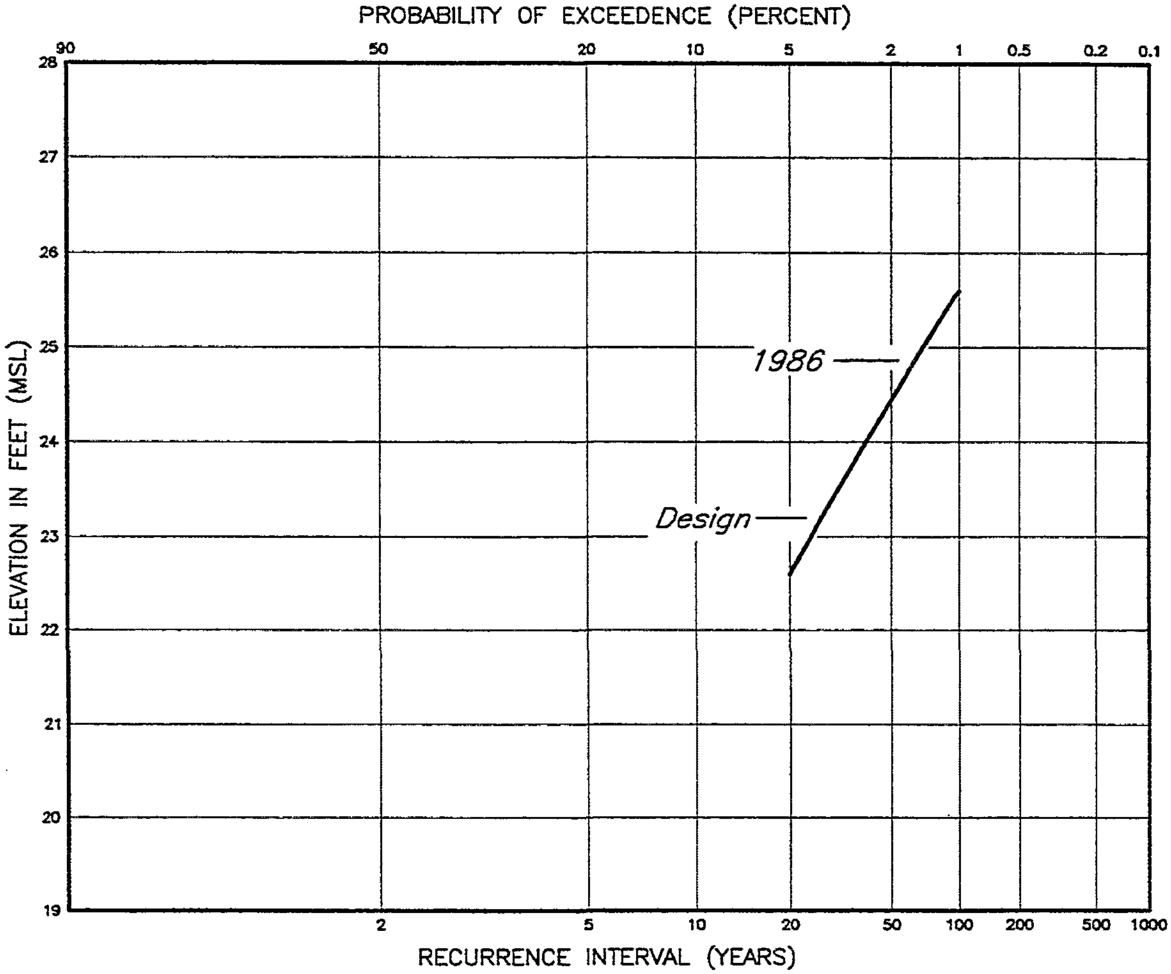


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
SACRAMENTO RIVER
AT COLLINSVILLE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 18



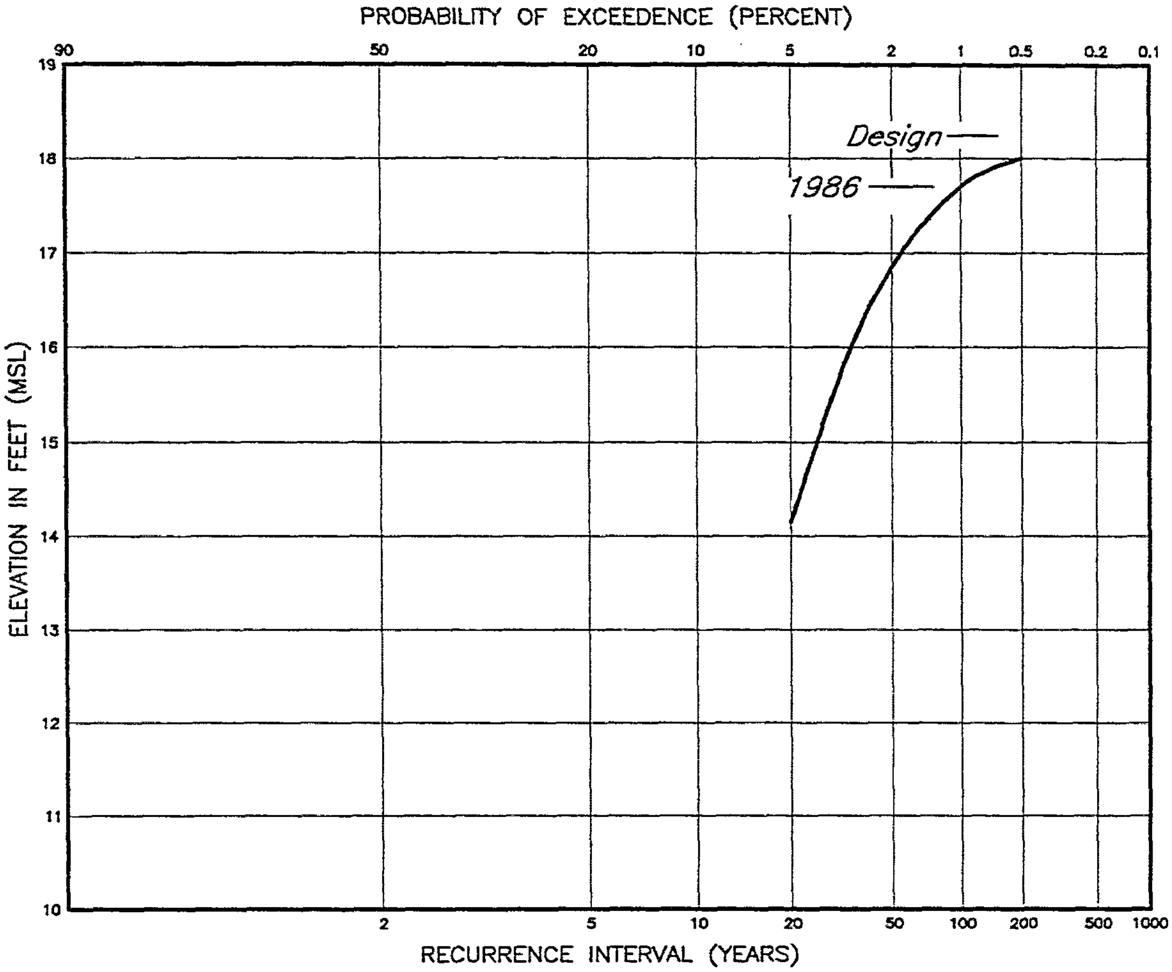
NOTE: Present condition (peak stage) stage-frequency relationship taken from the Hydrology Office Report, "American River and Sacramento Metro Investigations, California," Corps of Engineers, January 1990.

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
YOLO BYPASS
NEAR LISBON**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 19

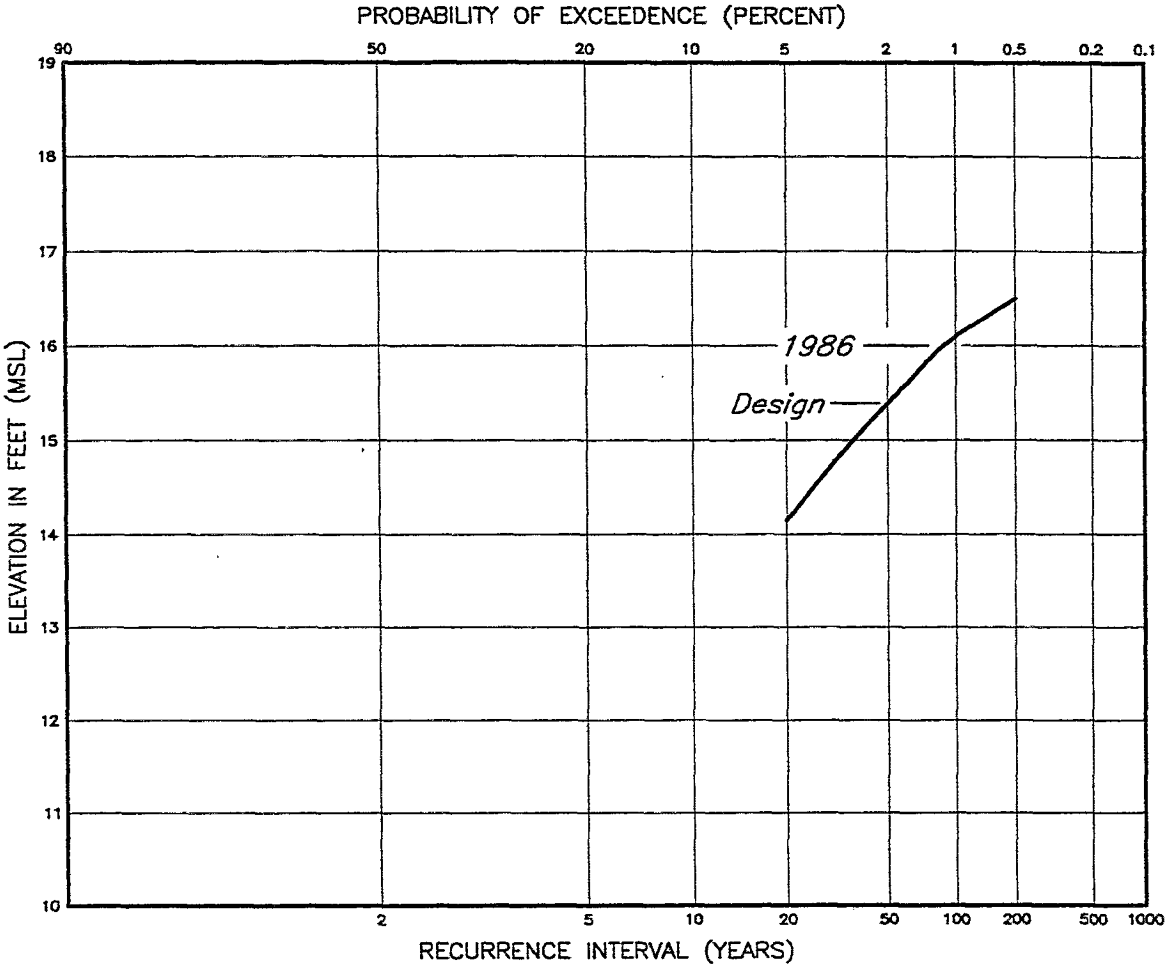


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE
YOLO BYPASS
NEAR RD 2068 PUMP STATION

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 20

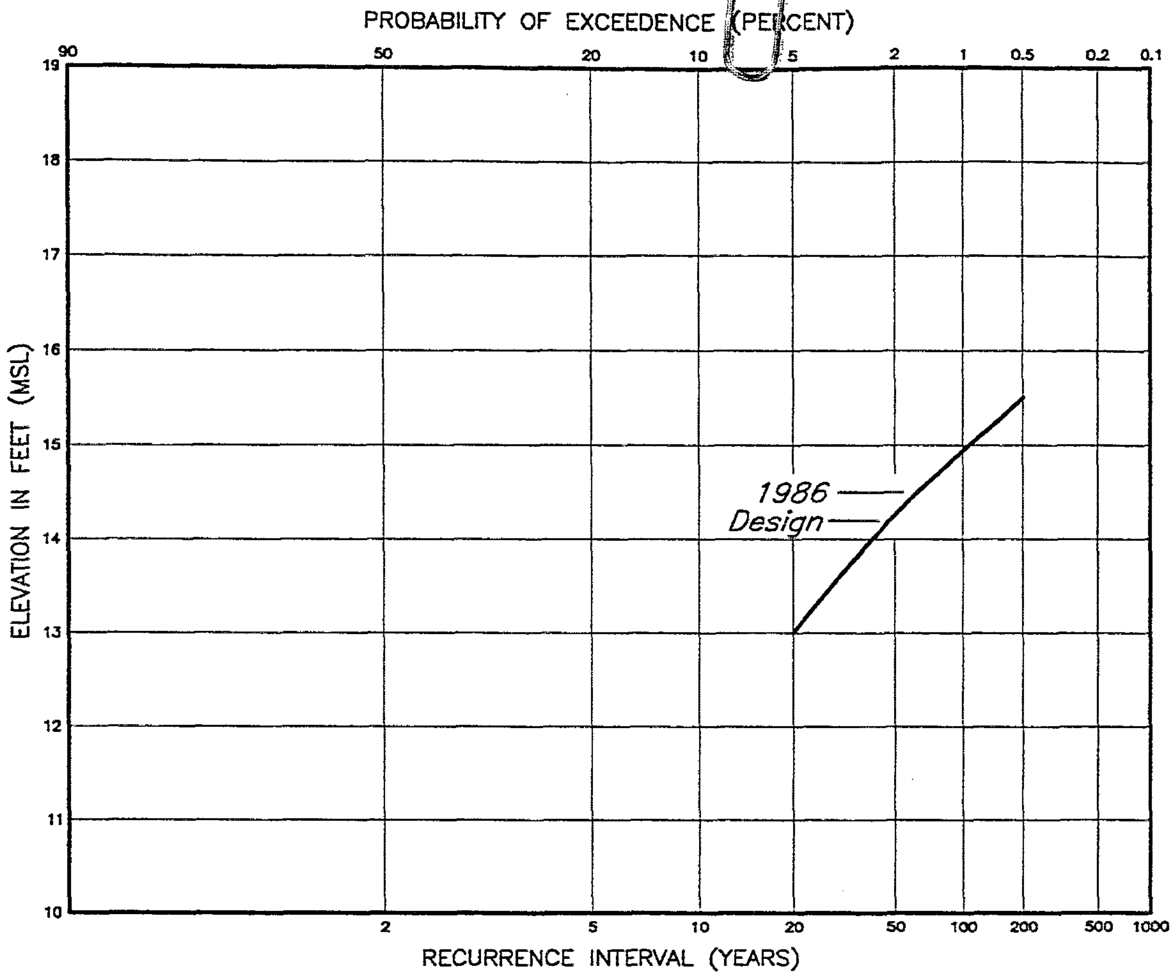


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE
YOLO BYPASS
AT CACHE SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 21

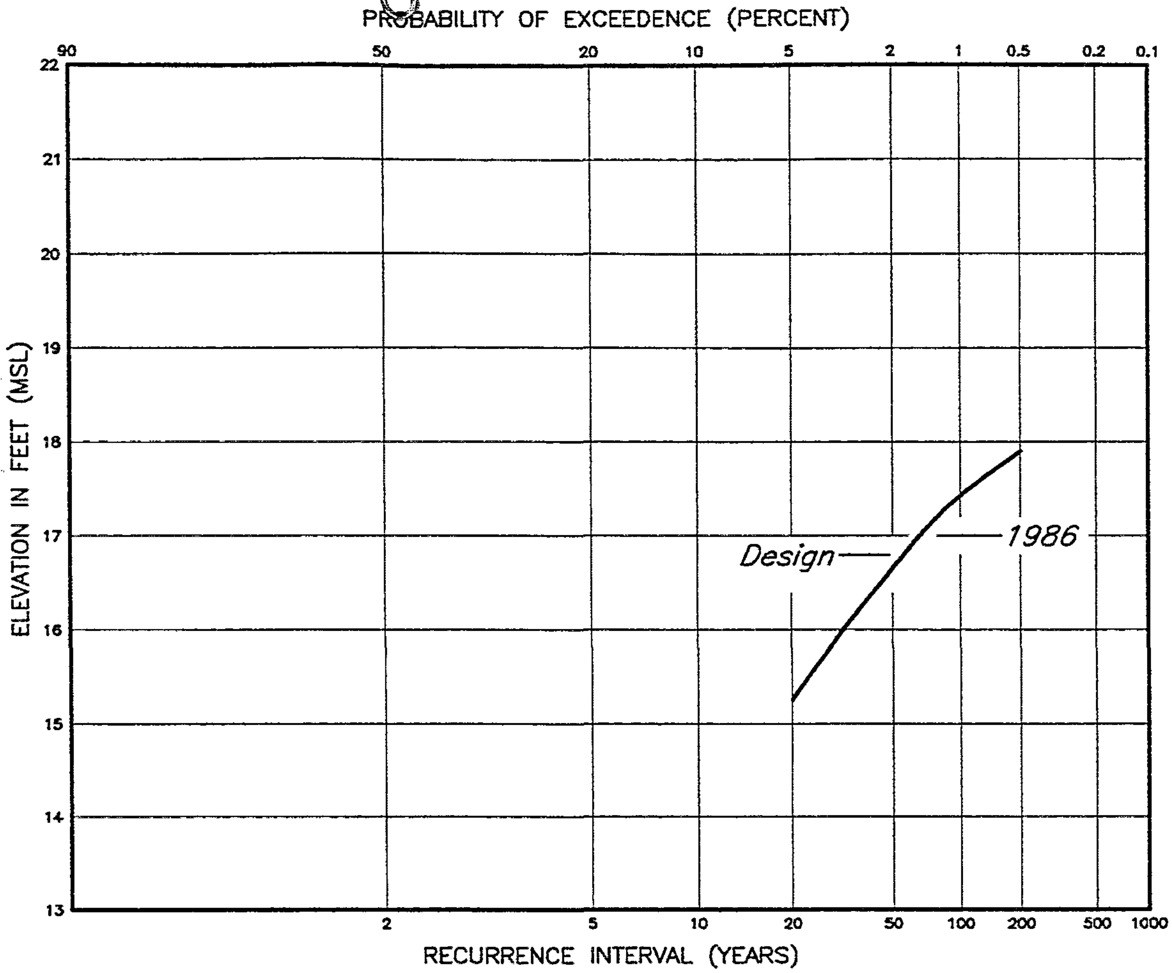


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE
YOLO BYPASS
AT LINDSEY SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 22

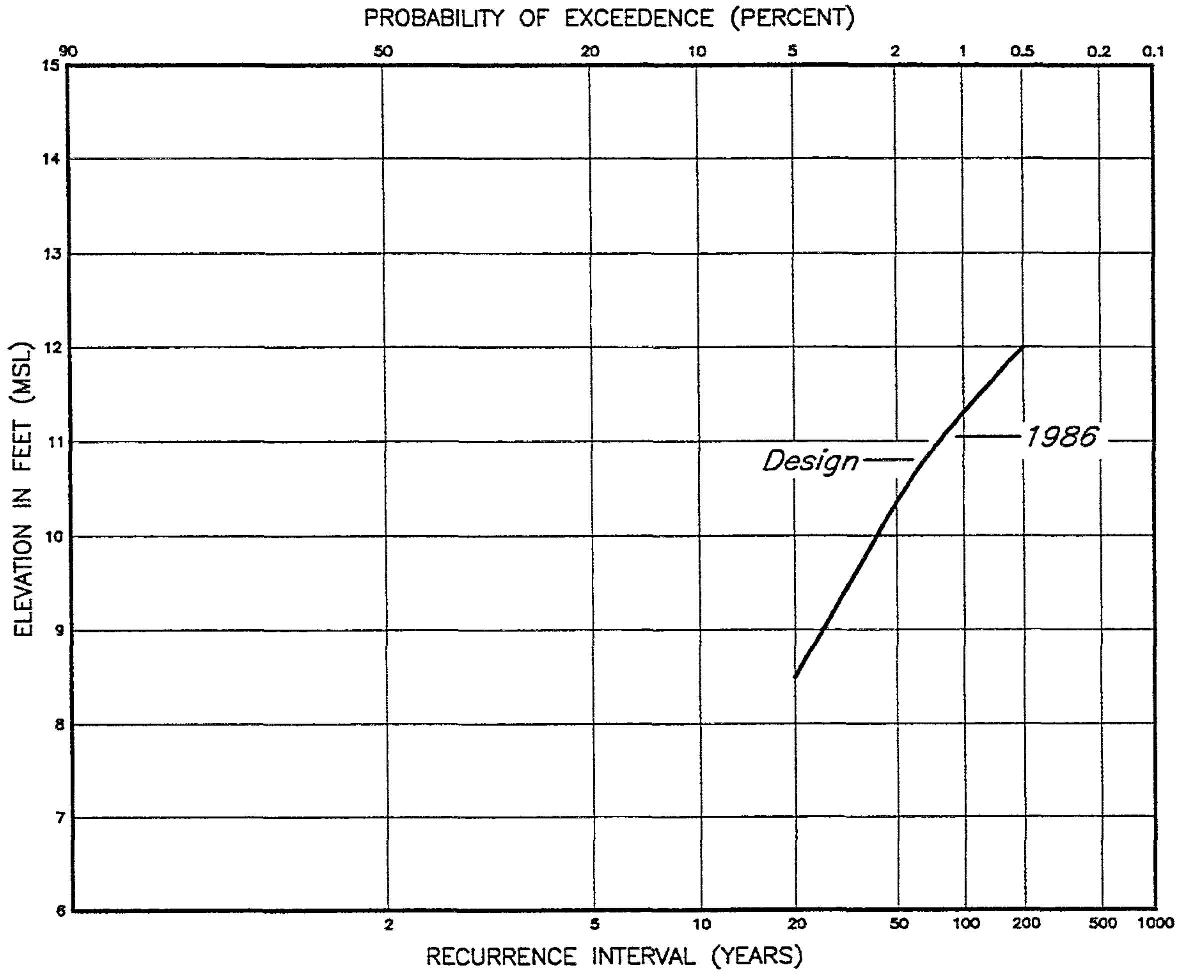


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE
MINER SLOUGH
AT CACHE SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 23



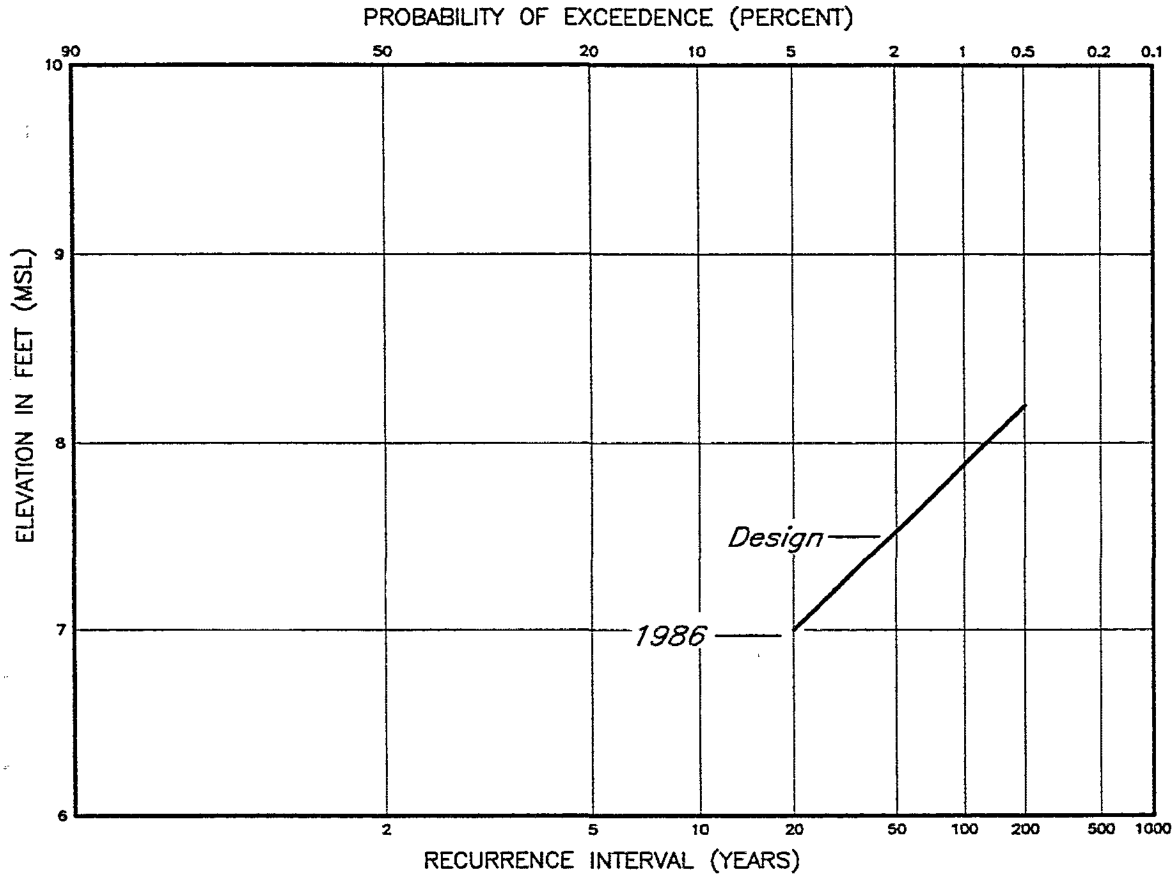
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE
STEAMBOAT SLOUGH
AT CACHE SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 24

C-103399

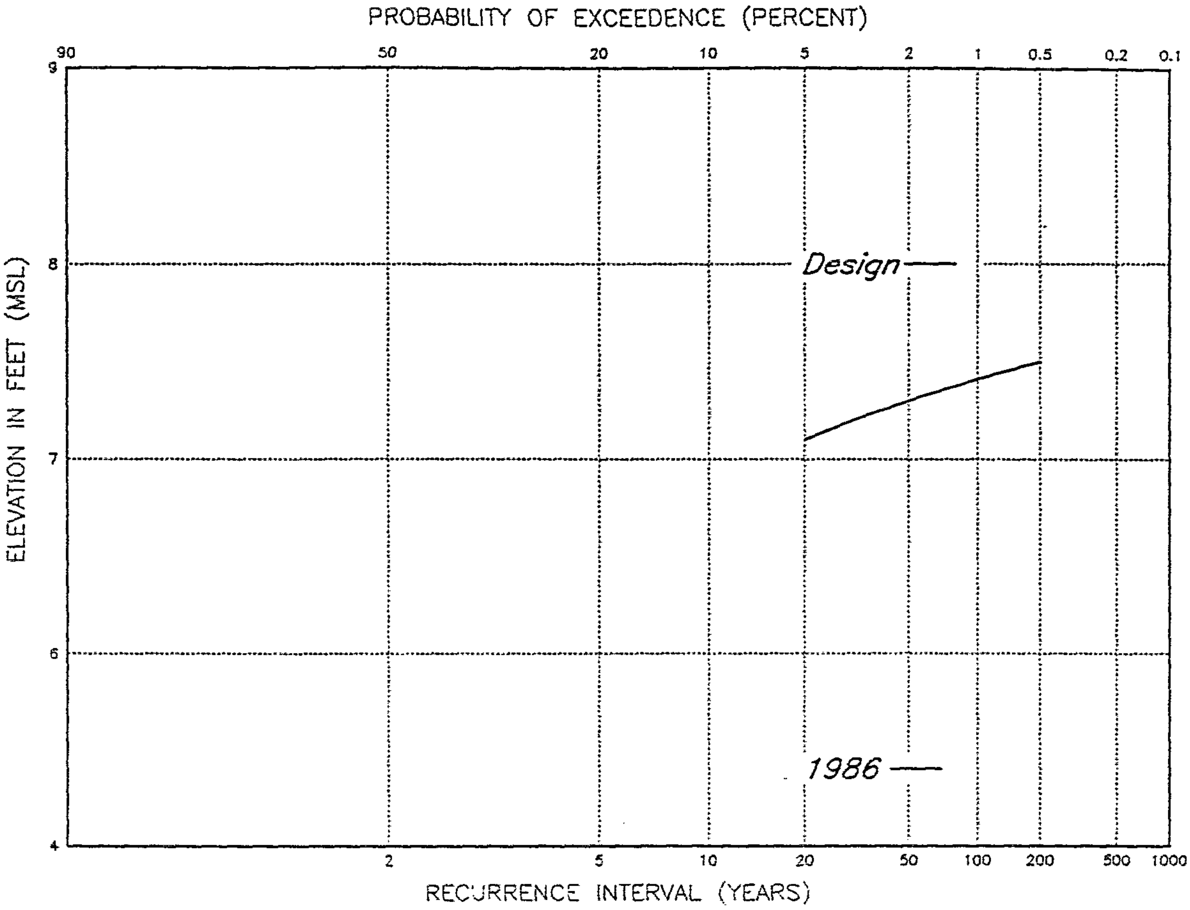


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
GEORGIANA SLOUGH
AT MOKELUMNE RIVER**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 25

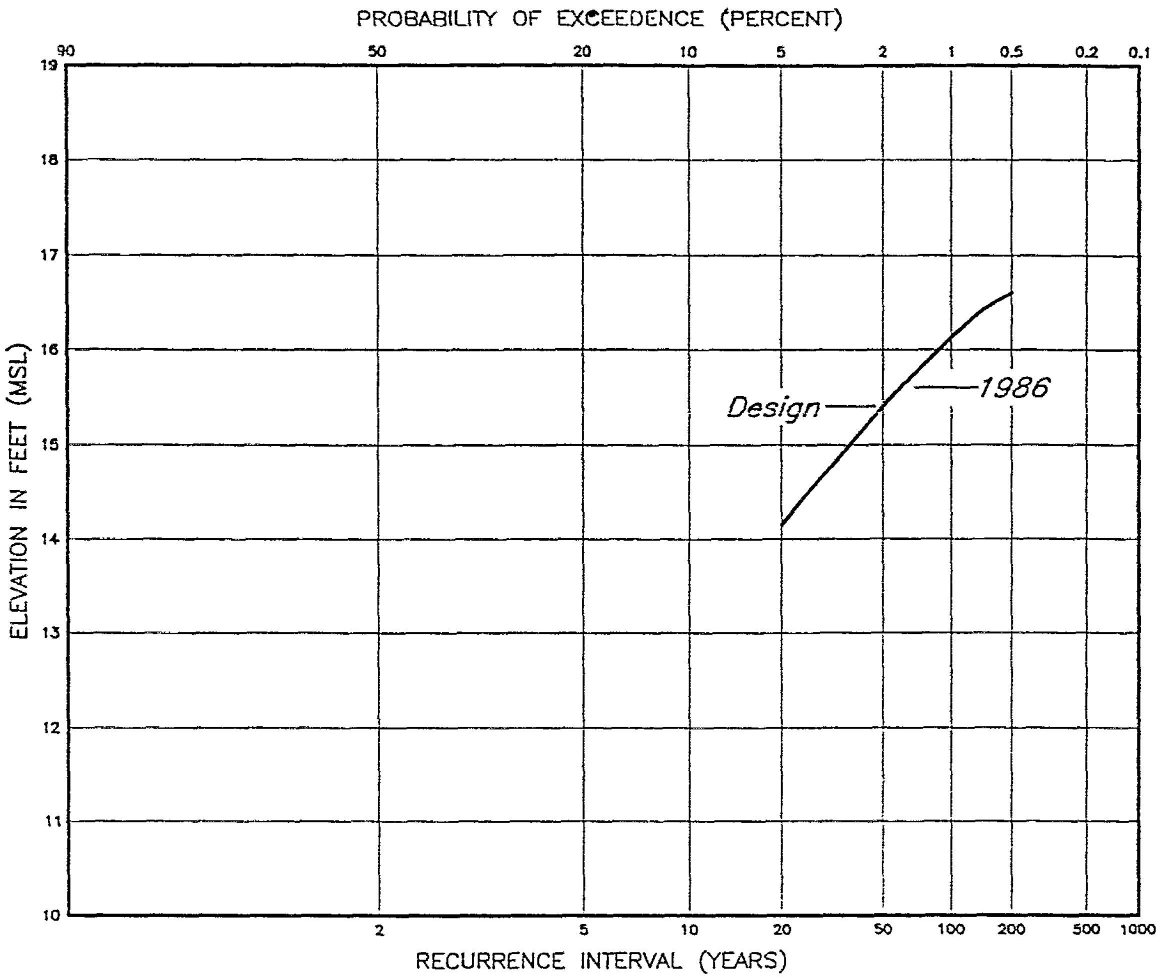


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
THREEMILE SLOUGH
AT SAN JOAQUIN RIVER**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 26

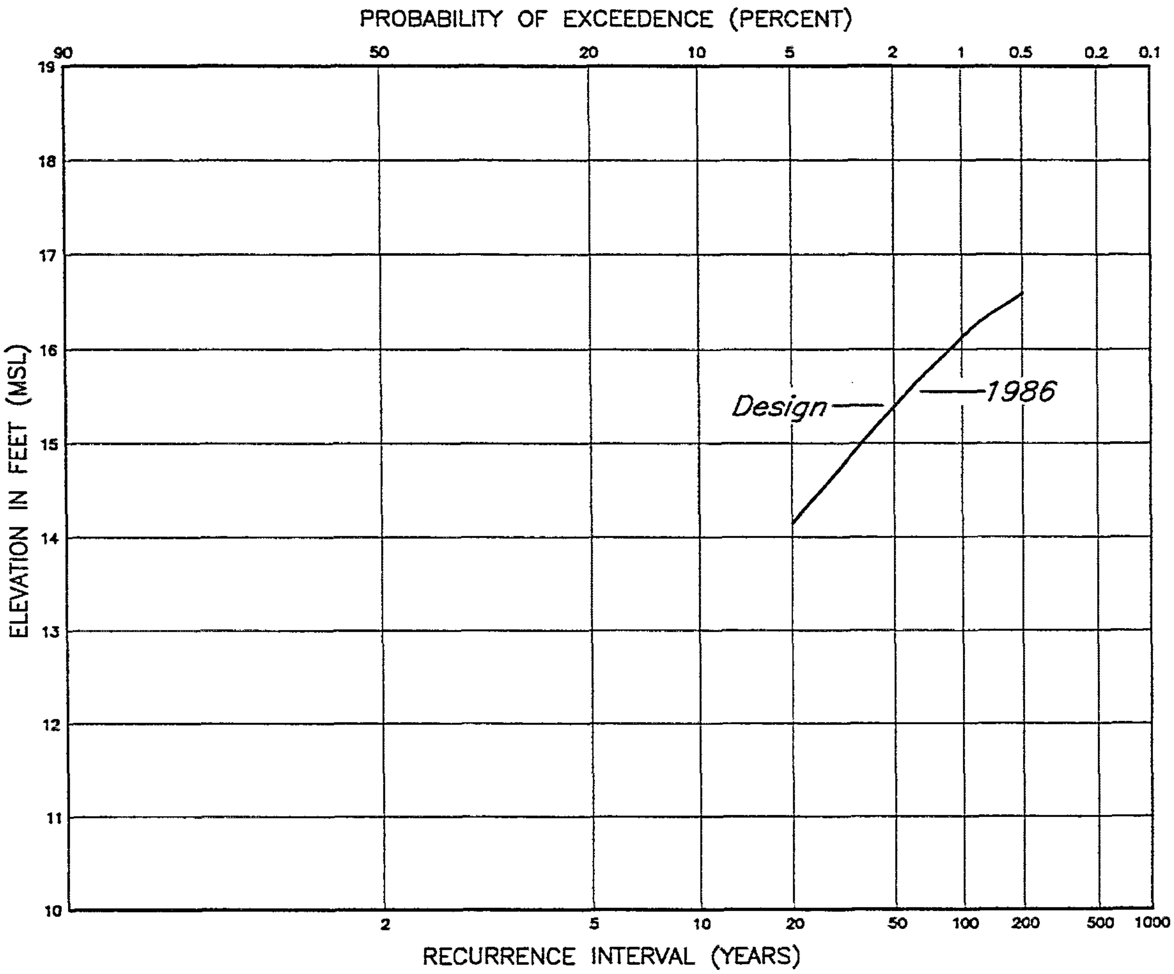


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE HAAS SLOUGH AT BUNKER STATION ROAD

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 27

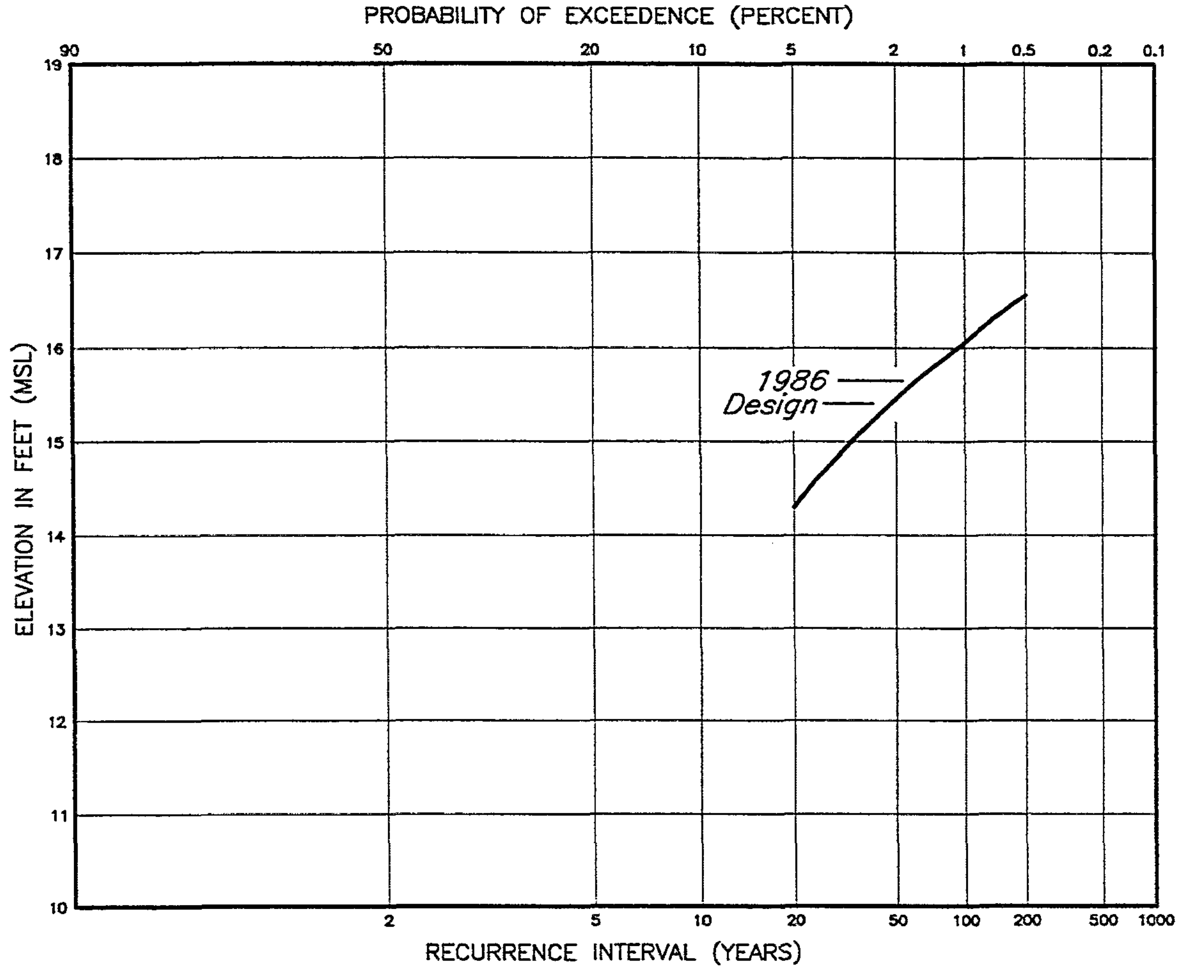


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
ULATIS CREEK
AT CACHE SLOUGH**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 28

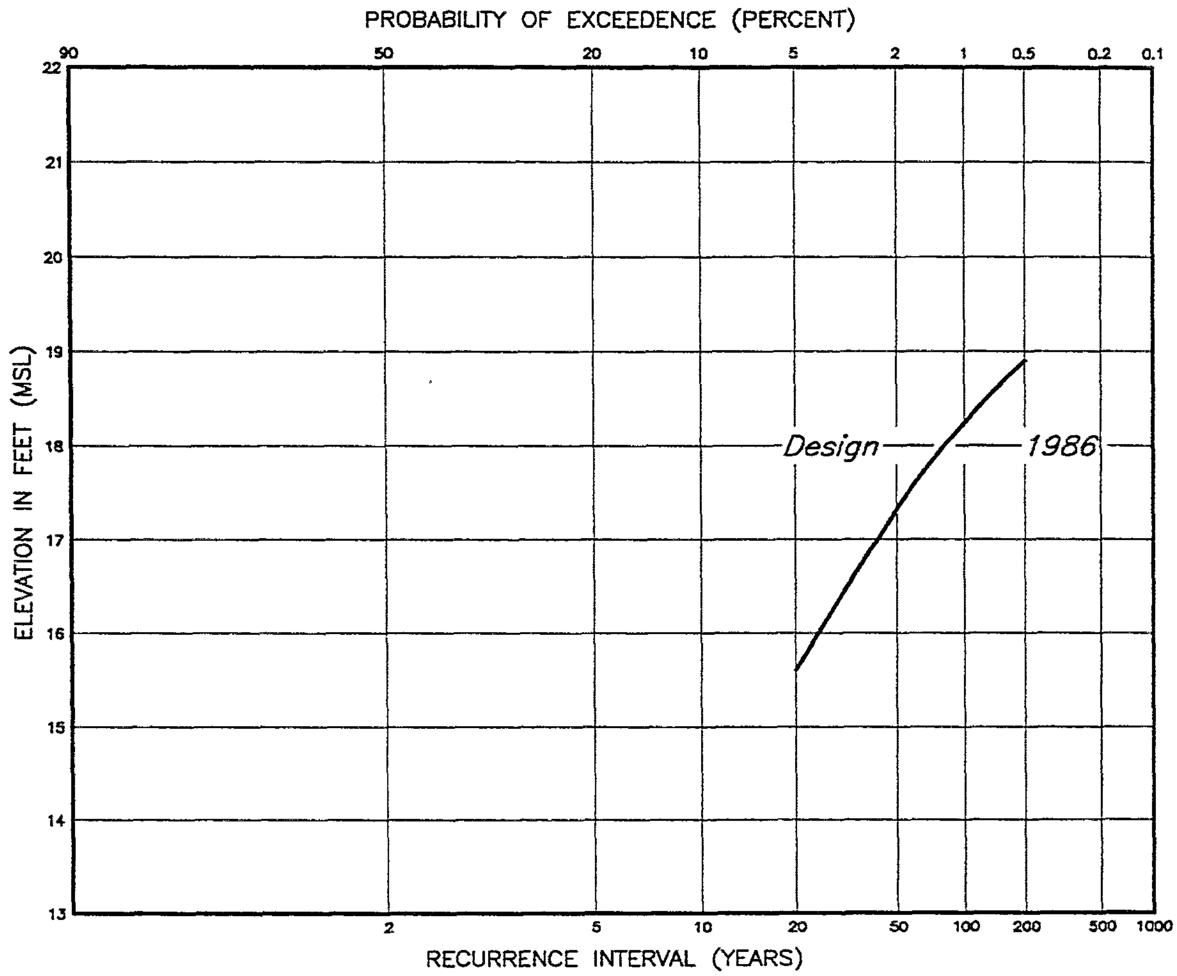


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE-FREQUENCY CURVE
HAAS SLOUGH
AT CACHE SLOUGH**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 29

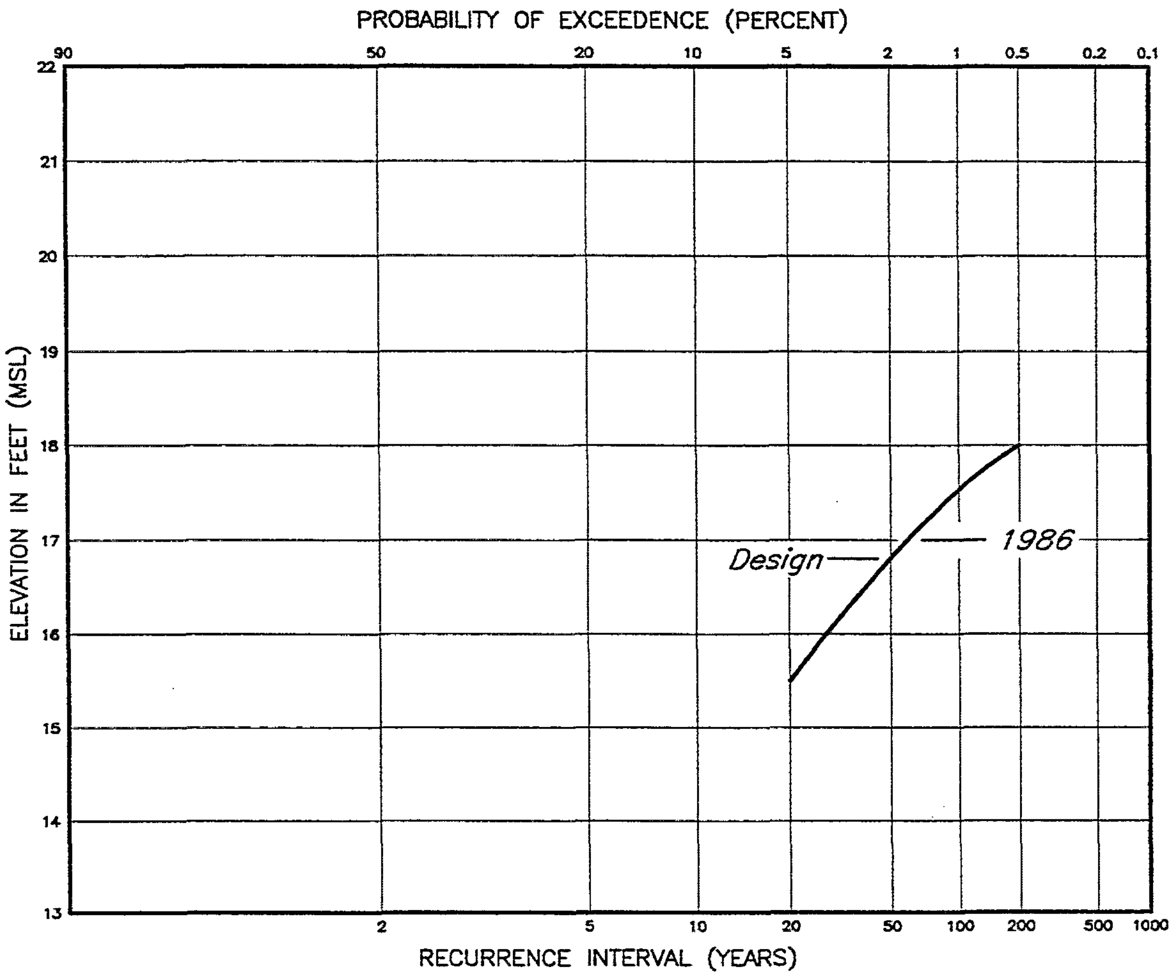


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE-FREQUENCY CURVE
ELK SLOUGH
AT SUTTER SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 30

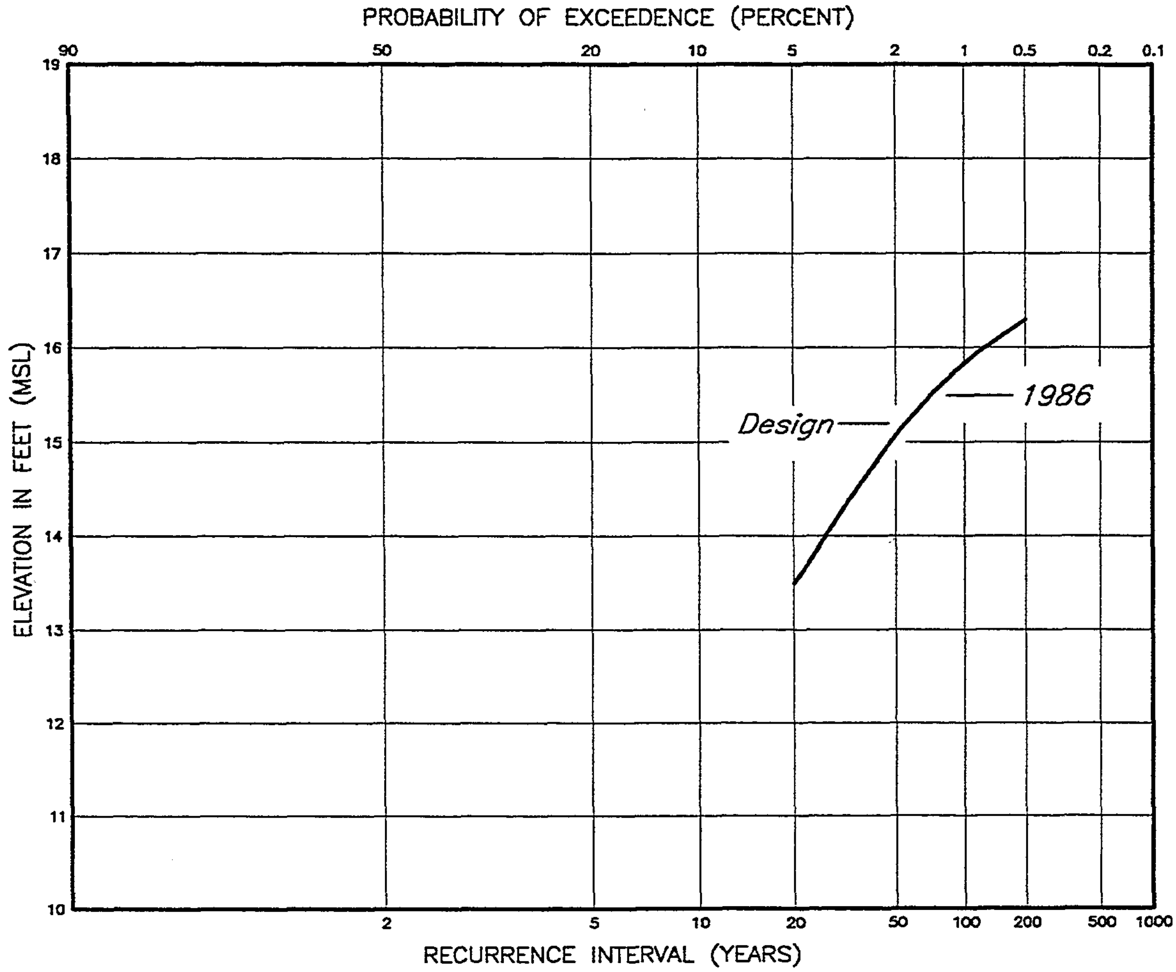


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**STAGE–FREQUENCY CURVE
SUTTER SLOUGH
AT MINER SLOUGH**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 31



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STAGE–FREQUENCY CURVE
SUTTER SLOUGH
AT STEAMBOAT SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 32

The discharge and stage-frequency relationships are considered representative of existing conditions in the study area and in the Sacramento River watershed. Most of the relationships were developed in conjunction with ongoing studies for the American River Watershed, Sacramento Metropolitan Area, and Westside Tributaries to Yolo Bypass Investigations and funded in part by the Sacramento River Flood Control System Evaluation (see references, Table 1).

Stage recorders are located at I-Street, Freeport, Snodgrass Slough, Walnut Grove, Rio Vista, and Collinsville on the Sacramento River; on Georgiana Slough at Mokelumne River; and on San Joaquin River at Threemile Slough. Short-term records of annual peak stage data were extended based on correlations with the other station records and the recorded and computed data plotted for each location. Curves were fitted to the plotted data to develop the segments of the stage-frequency curves shown in this report. Curves were extended beyond the plotted points based on hydrologic models developed previously to determine water-surface profiles for the infrequent floods.

Stage-frequency relationships were also developed for those locations without stage recorders based on correlations with the stage-frequency curves determined above and on computed water-surface profiles for specific flood events.

Only partial curve segments of the stage and discharge-frequency relationships have been plotted to adequately cover the range of recurrence intervals necessary to accomplish the economic evaluations. For the curve segments shown and for recurrence intervals equal to or less than 200 years, the following conditions apply:

- Levee breaching on the Yuba, Sacramento, and American Rivers will take place according to conditions specified in Appendix K, "American River Watershed Investigation, California," Corps of Engineers, December 1991.

- Releases at Folsom Dam cannot be controlled for floods with a recurrence interval less than about 70 years.

Significant physical changes have occurred and are occurring in the Sacramento River Basin, particularly in and adjacent to the study area, that have an impact on flow patterns, flow conveyance, flood stages, and direct runoff. Since the February 1986 flood, levee embankments and floodwalls have been raised, levees repaired, new levees constructed in the Cache Creek Settling Basin, and flood gates installed at locations where levee overflow and flooding occurred in 1986. In addition, following the 1986 flood, accumulated sediments were removed from Colusa Bypass and Sediment Basin, from Tisdale Bypass, and from

Yolo Bypass just upstream and downstream from Fremont Weir (overflow structures on the Sacramento River upstream of the study area).

If the February 1986 rainfall event were to occur under physical conditions existing today, the above changes would result in peak flood stages and floodflows within the study area different from those recorded in 1986. Because of these and other physical changes, hydrologic models were developed to simulate physical conditions that exist today in the basin. As such, recurrence intervals associated with the recorded peak flood stages and floodflows of the 1986 flood (as shown in Figures 8 through 32) represent a hypothetical flood resulting from a different combination of meteorological and physical conditions than actually existed in February 1986.

Peak flood stages and floodflows of the 1986 flood were, in many cases, the maximums recorded (for the systematic records) in the study area. Floodflows reached maximum stages on the Sacramento River at Freeport, at Snodgrass Slough, at Walnut Grove, at Rio Vista, and at Collinsville; on Georgiana Slough at Mokelumne River; and on Yolo Bypass near Lisbon. Maximum floodflows were also reached on the Sacramento River at Freeport and on Yolo Bypass near Lisbon. A comparison of the 1986 peak flows and stages of Table 3 with the design flows and stages of Table 4 indicates that the 1986 peak flows exceeded design flows in Sacramento River at Freeport and in Yolo Bypass downstream of Putah Creek, and that the 1986 peak flood stages exceeded design stages in Sacramento River between Elk Slough and Walnut Grove and in Yolo Bypass near Lisbon. In addition, the 1986 high-water mark data (which include the effect of wave action) of Plates 5 through 19 indicate minimum freeboards less than 3 feet on Willow Slough Bypass, Sacramento River, Yolo Bypass, Georgiana Slough, Miner Slough, Cache Slough (see upper photograph of Figure 6), Haas Slough, Lindsey Slough, and Threemile Slough.

The <u>existing condition</u> stage-frequency relationships indicate that the 1986 high-water mark information (the static water-surface elevation plus wind setup) represents about a 6-year recurrence interval at Cache Creek (Figure 8, not reliable due to subsidence and degradation), about a 70-year recurrence interval on the Sacramento River between I-Street and Threemile Slough (Figures 9 through 18), about a 50-year to 100-year recurrence interval on Yolo Bypass (Figures 19 through 22), and about a 50-year to 80-year recurrence interval on most of the sloughs (Figures 23 through 32) within the study area.

For the levee channel reach of the Sacramento River between the American River and Sutter Slough, the design flow is 110,000 cfs (Table 3). On February 20, the Freeport gage measured flows of 117,000 cfs at 25.11 feet mean sea level just above design (see Table 3 and Plate 8, sheet 1 of 4). Downstream of the

TABLE 4

DESIGN FLOWS AND STAGES

Location	Design Flow (cfs)	Design Stage (msl)
Cache Creek		
at Highway 113	30,000 [1]	66.6 [1]
Willow Slough Bypass		
at confluence with Yolo Bypass	6,000	25.8
Putah Creek		
at confluence with Yolo Bypass	62,000	24.1
Sacramento River		
at Freeport	110,000	25.3
at Clarksburg	110,000	22.8
just downstream Sutter Slough	84,500	18.3
just downstream Steamboat Slough	56,500	17.5
just downstream Georgiana Slough	35,900	14.2
at Isleton	35,900	11.0
just downstream Cache Slough	579,000	10.0
at Rio Vista Bridge	579,000	9.6
just downstream Threemile Slough	514,000	8.9
Yolo Bypass		
just downstream Putah Creek	490,000	24.1
just downstream Miner Slough	500,000	16.6
just downstream Cache Slough	500,000	15.3
Elk Slough		
at junction with Sacramento River		18.0
at junction with Sutter Slough		18.0
Sutter Slough		
just downstream Sacramento River	25,500	18.2
just downstream Miner Slough	15,500	16.8
Georgiana Slough		
just downstream Sacramento River	20,600	14.5
just upstream Mokelumne River	20,600	7.5
Steamboat Slough		
just downstream Sacramento River	28,000	17.5
just downstream Sutter Slough	43,500	15.2
at junction with Cache Slough		10.8
Miner Slough		
just downstream Sutter Slough	10,000	16.8
just upstream Yolo Bypass	10,000	16.7
Haas Slough		
just upstream Cache Slough		15.4
Cache Slough		
at junction with Ulatis Creek		15.4
at junction with Haas Slough		15.4
Just upstream Yolo Bypass		15.4
Ulatis Creek		
just upstream Cache Slough		15.4
Lindsey Slough		
just upstream Yolo Bypass		14.3
Threemile Slough		
just downstream Sacramento River	65,000	9.0

[1] Not a valid flow based on current m.s.l

intersection of Sutter Slough with the Sacramento River, flows are distributed into Sutter Slough and Steamboat Slough, causing design flows of the Sacramento River to decline to 35,900 cfs.

Water-surface profiles on the Sacramento River (Plate 8, sheets 1 through 4) as well as the discharge frequency curves on the Sacramento River (Figures 9 through 16) indicate (gages and high water marks), that the 1986 flood was at or above design water surface until the Sacramento River reaches Threemile Slough (Figure 17). At Threemile Slough and Collinsville (Figure 18), the 1986 flood was below design as flows in the San Joaquin River were low. Between the junction of the Sacramento River with Cache Slough and its junction with Threemile Slough, the Sacramento River design flow is 579,000 cfs. Between Threemile Slough and Collinsville, the Sacramento River design flow is 514,000 cfs.

As discussed in the geotechnical reports and in the following sections, the slope stability analysis performed for selected levee cross sections was based on a peak flood stage of 3-day duration. (The phreatic surface elevations within the levee embankments were developed based on the assumption that the peak flood stage would remain at or near the design water surface for 3 days.) For the above analysis, stage hydrographs within the study area were plotted for the February 1986 flood (see Figures 33 through 42). As indicated by the hydrographs, peak flood stages remained at or near the peak (within 1 to 3 feet depending on location) for a 3-day interval. For the Sacramento River and Yolo Bypass (Figures 33 through 40) stage hydrographs, flood stages remained within 2 feet of the peak for a 3-day duration. Since the peak flows and stages at these locations were at or near design conditions, the 3-day duration assumption is appropriate for the Sacramento River and Yolo Bypass. For Georgiana Slough at the Mokelumne River (Figure 41) and the Sacramento River Deep Water Ship Channel (Figure 42), peak flood stages remained with 2 feet of the peak for a 3-day duration, so the 3-day duration seems appropriate for the sloughs in the Delta.

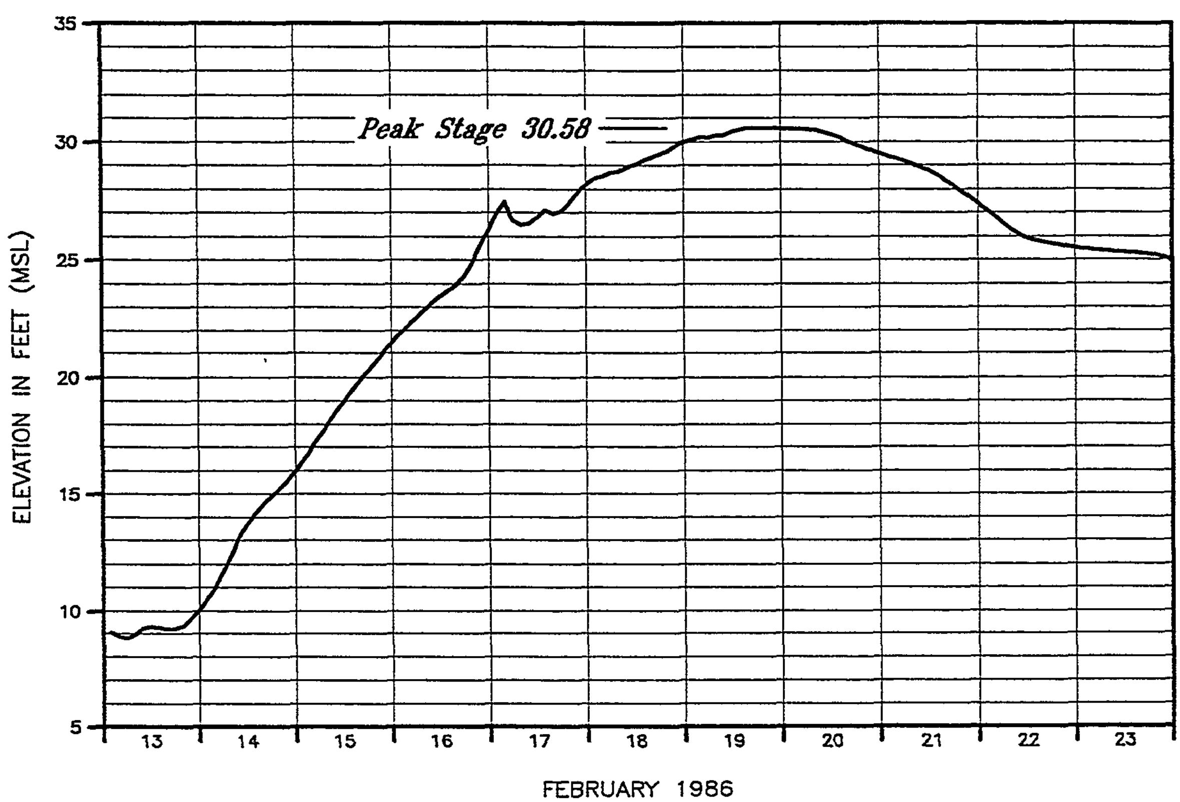
For the various tributary streams (Cache Creek, Willow Slough Bypass, and Putah Creek), a design flood stage of 3-day duration is probably not warranted. If levee reconstruction is being considered for the levees on the tributary streams, phreatic surfaces would be determined based on a design flood of lesser duration. A more detailed analysis of phreatic surfaces would be accomplished in future engineering and design efforts.

A discharge versus elevation relationship was plotted for Cache Creek at Yolo (Figure 43) showing various relationships of seven curves from 1961 to present. Due to subsidence and degradation, the validity of the current rating curve is in question.

The above information in conjunction with prior hydraulic and hydrologic models developed for the American River and Sacramento Metropolitan Area investigations was used in developing water-surface profiles in the study area for design conditions and for floods equal to or greater than the flood which occurred in February 1986.

For the Yolo Bypass near Woodland (just downstream of the confluence with Cache Creek), the design flow is 377,000 cfs and the stage is 31.3 feet. The 1986 peak flow and stage was 374,000 cfs and 31.4 feet, respectively (from published U.S. Geological Survey records), which suggests that this part of the Yolo Bypass was generally functioning as designed in February 1986 (within the limits of accuracy of the computed flows and stages). At Lisbon on 10 February 1986, peak stage in the Yolo Bypass was at 24.88 feet mean sea level (Table 3) with flows estimated at 495,000 to 509,000 (there are no measured flows at Lisbon) cfs, which was above the design flow of 490,000 cfs. Water-surface profiles of the Yolo Bypass (Plate 9, sheets 1 and 2) indicate that the 1986 flood water-surface elevations were 1 to 3 feet above the design elevations in several places. Some of this elevated water-surface elevation was due to wind-generated wave wash. Stage-frequency curves for Yolo Bypass (Figures 19 through 22) show the 1986 flood to be above design elevation.

Measured flow data are not available for the Delta sloughs or the Sacramento River downstream from Freeport. Water-surface profiles (Plates 9 through 14) and stage frequency curves (Figures 23 through 25 and Figures 27 through 32) indicate the February 1986 flood elevation was generally within 1 foot above or below the design elevation for most of the sloughs. For Threemile Slough, however, the 1986 flood water surface was 2 to 5 feet below the design water surface (Plate 18) and stage-frequency curve (Figure 26), based on the water-surface profile.



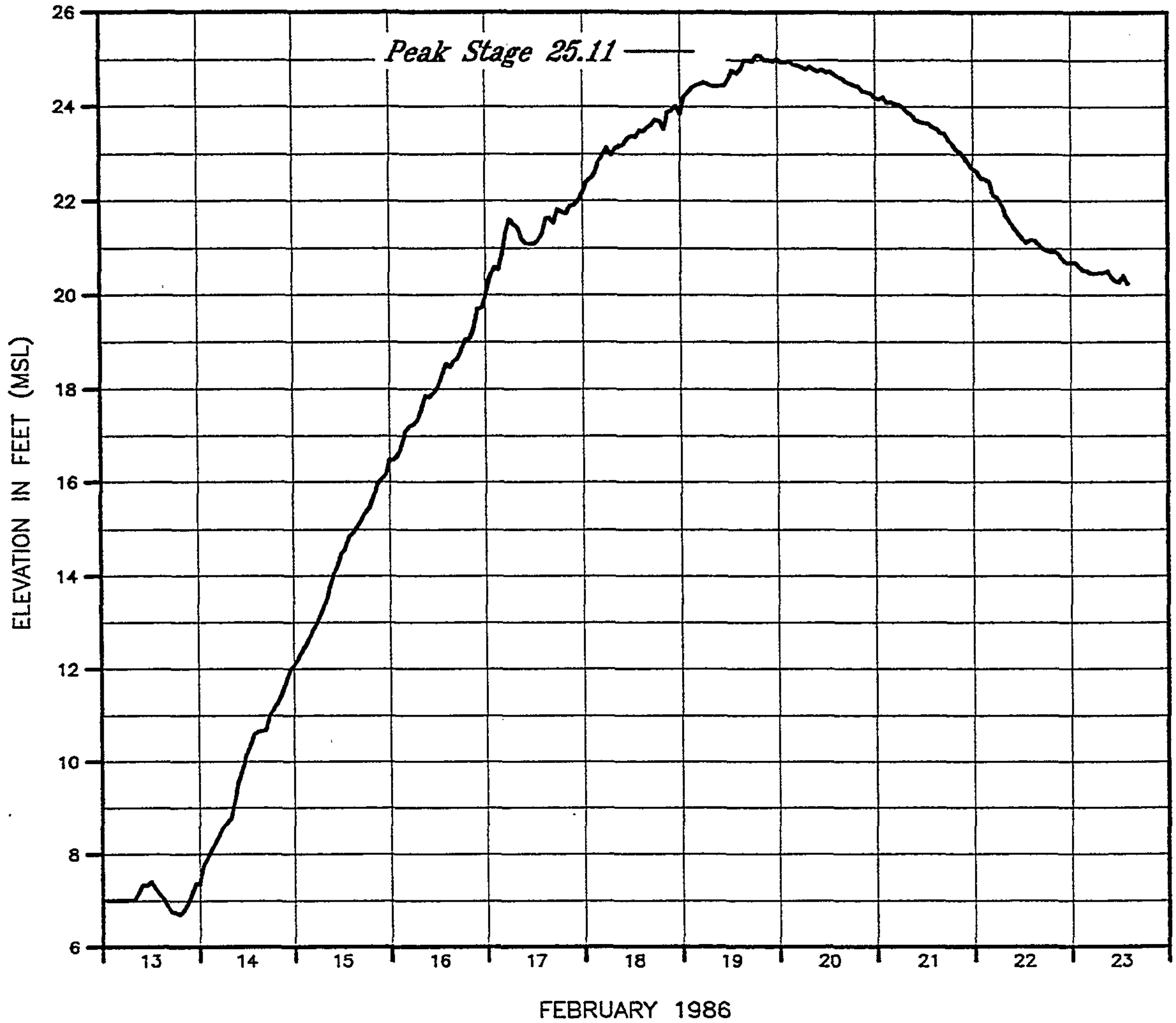
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

FEBRUARY 1986 FLOOD EVENT STAGE HYDROGRAPH

SACRAMENTO RIVER AT I-STREET

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 33



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

FEBRUARY 1986 FLOOD EVENT STAGE HYDROGRAPH

SACRAMENTO RIVER AT FREEPORT

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 34

C-103414

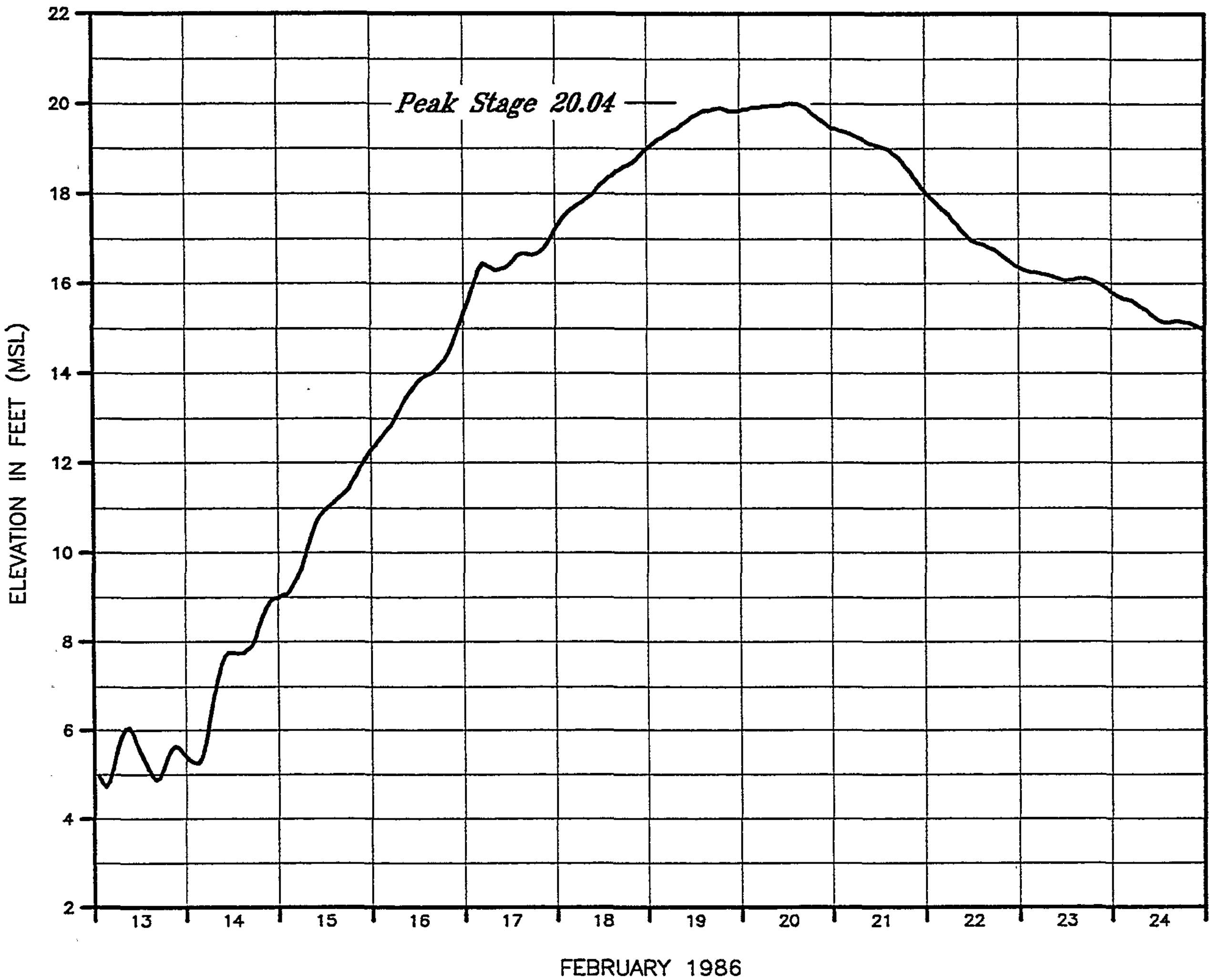
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

FEBRUARY 1986 FLOOD EVENT
STAGE HYDROGRAPH

SACRAMENTO RIVER
AT HOOD

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 35



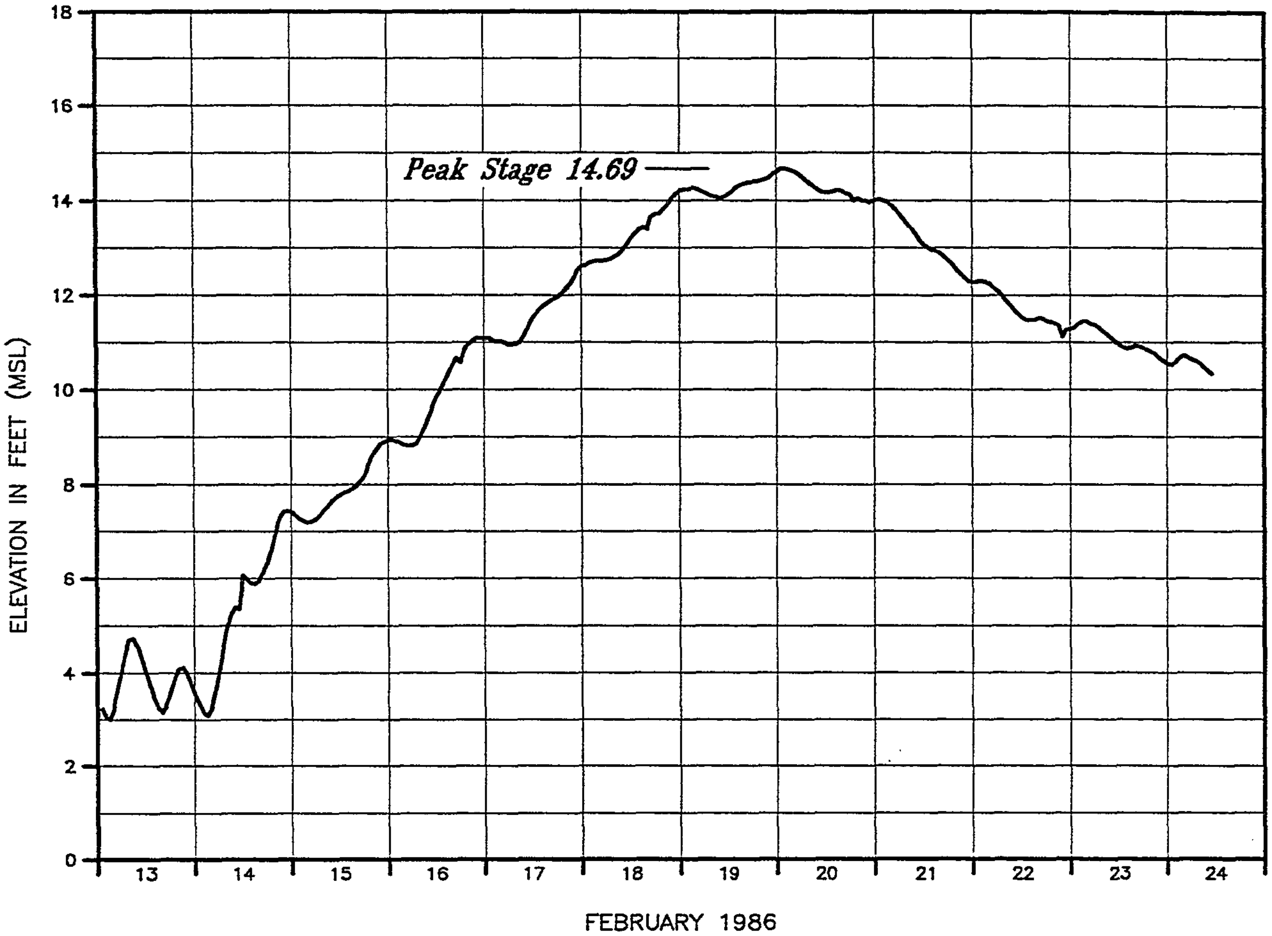
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

FEBRUARY 1986 FLOOD EVENT STAGE HYDROGRAPH

SACRAMENTO RIVER AT SNODGRASS SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 36



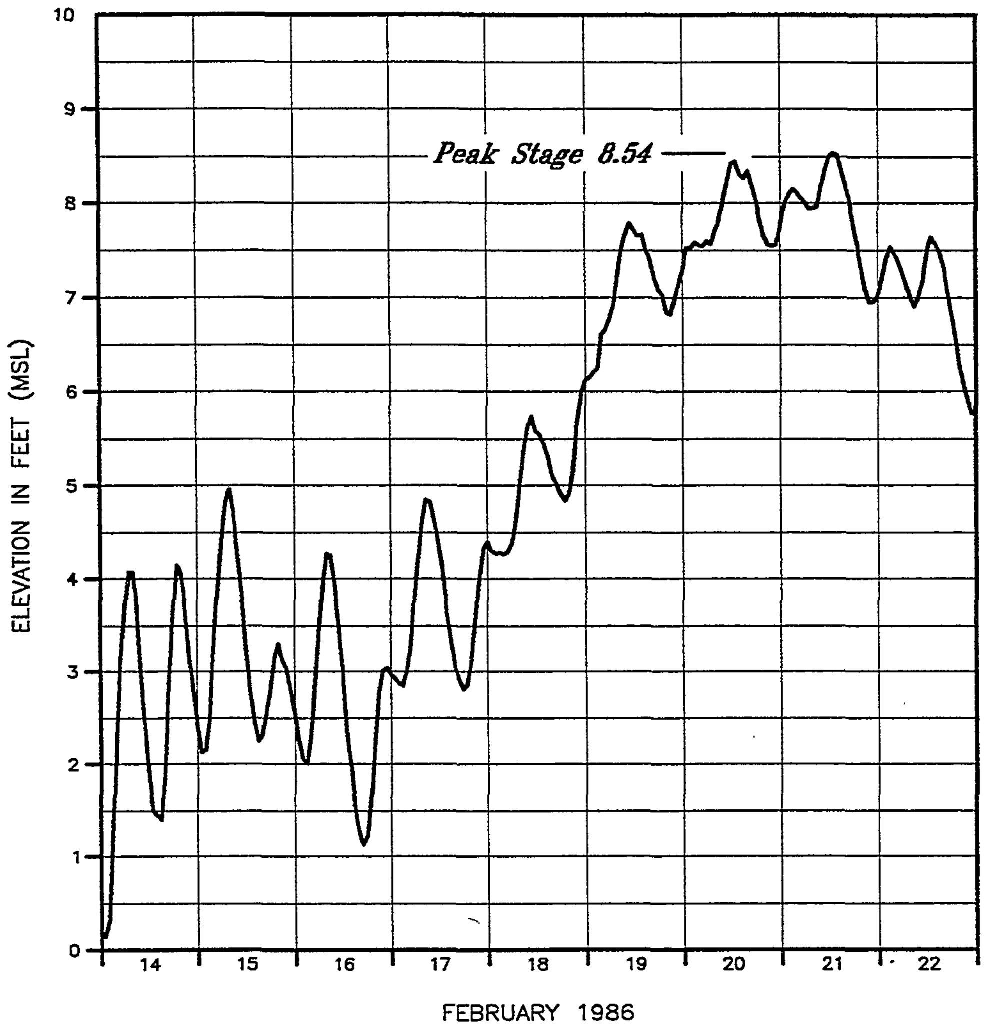
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

FEBRUARY 1986 FLOOD EVENT
STAGE HYDROGRAPH

SACRAMENTO RIVER
AT WALNUT GROVE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 37

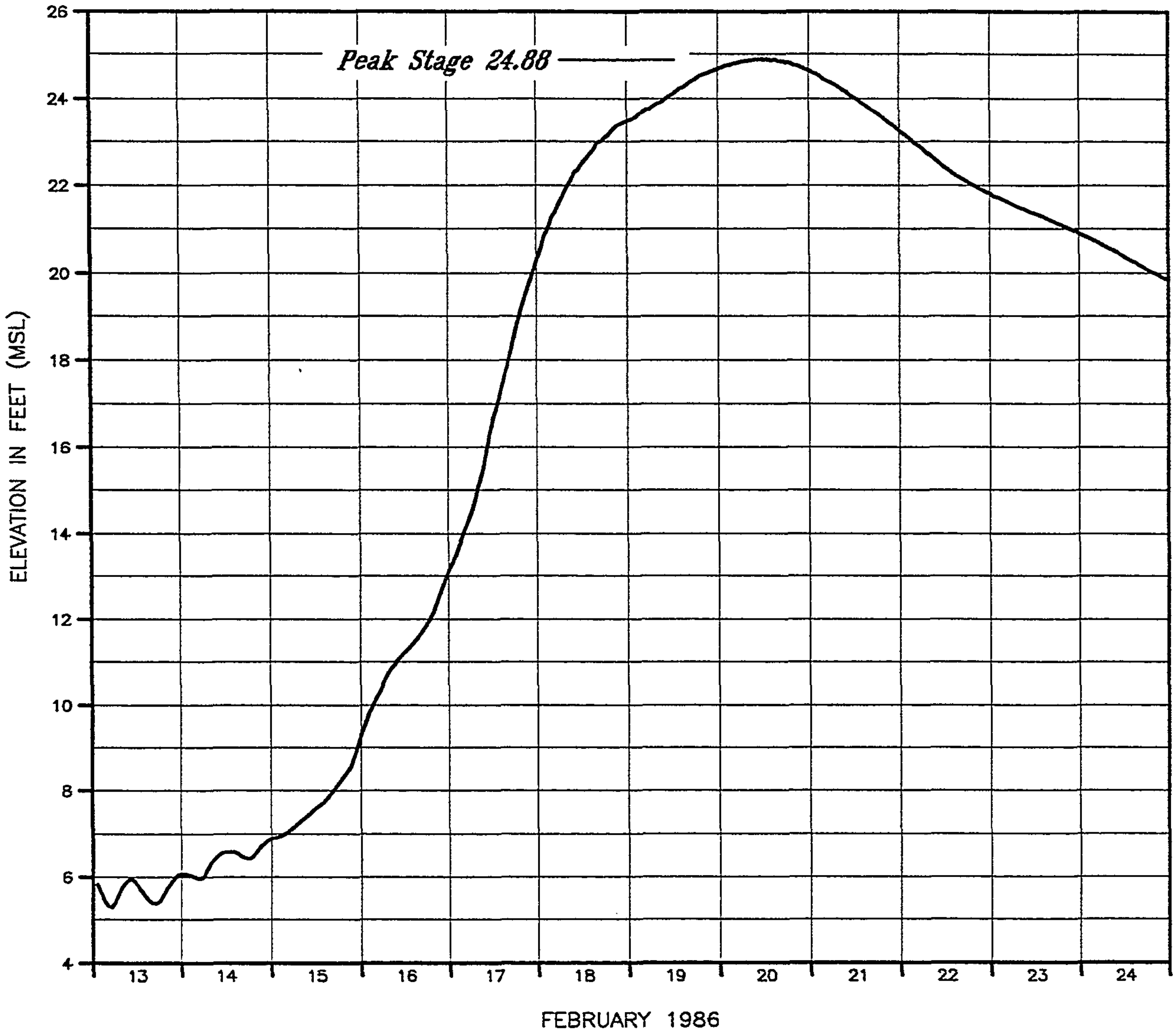


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

FEBRUARY 1986 FLOOD EVENT
STAGE HYDROGRAPH
SACRAMENTO RIVER
AT RIO VISTA

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 38



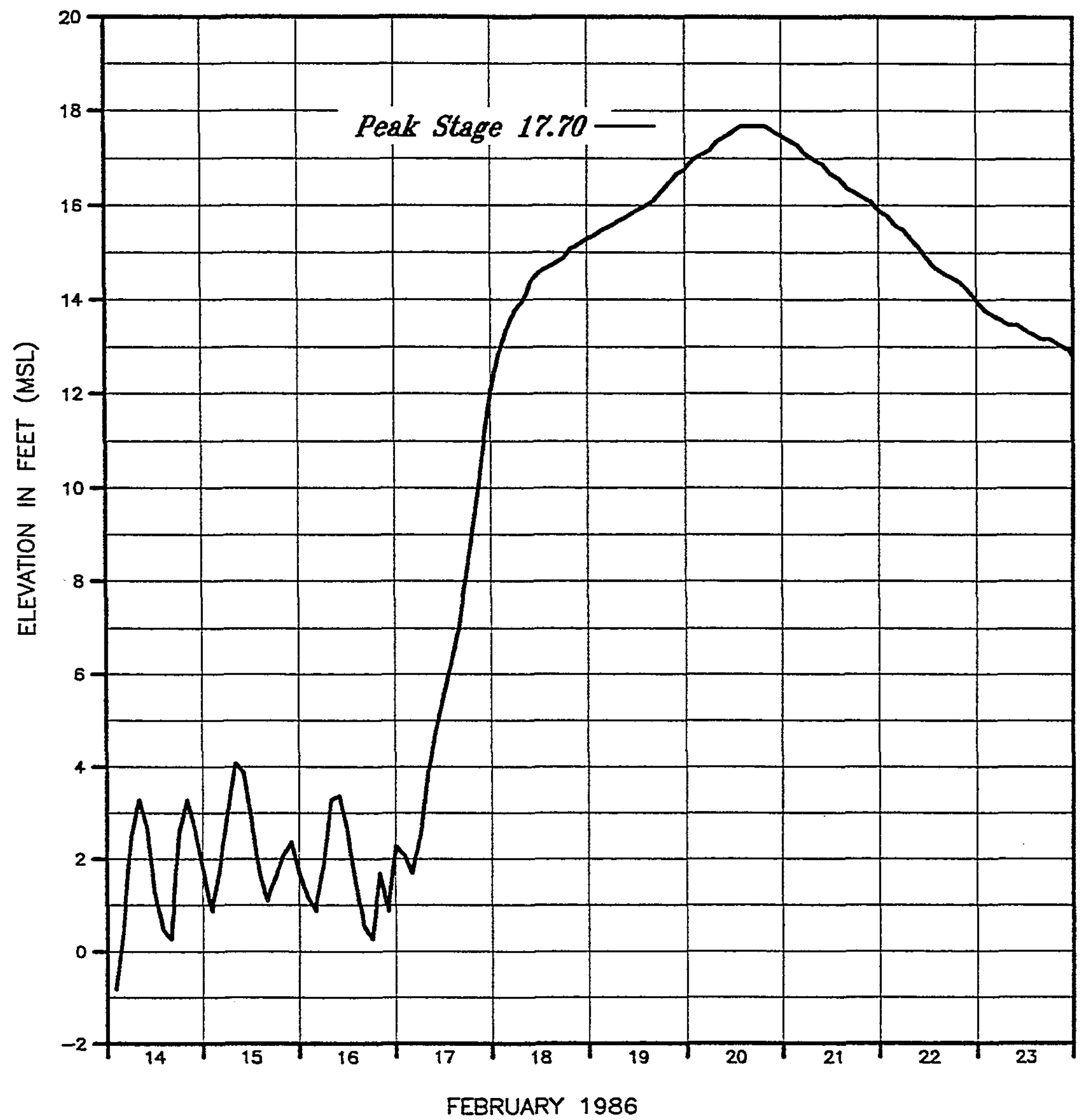
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**FEBRUARY 1986 FLOOD EVENT
STAGE HYDROGRAPH**

**YOLO BYPASS
AT LISBON**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 39



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

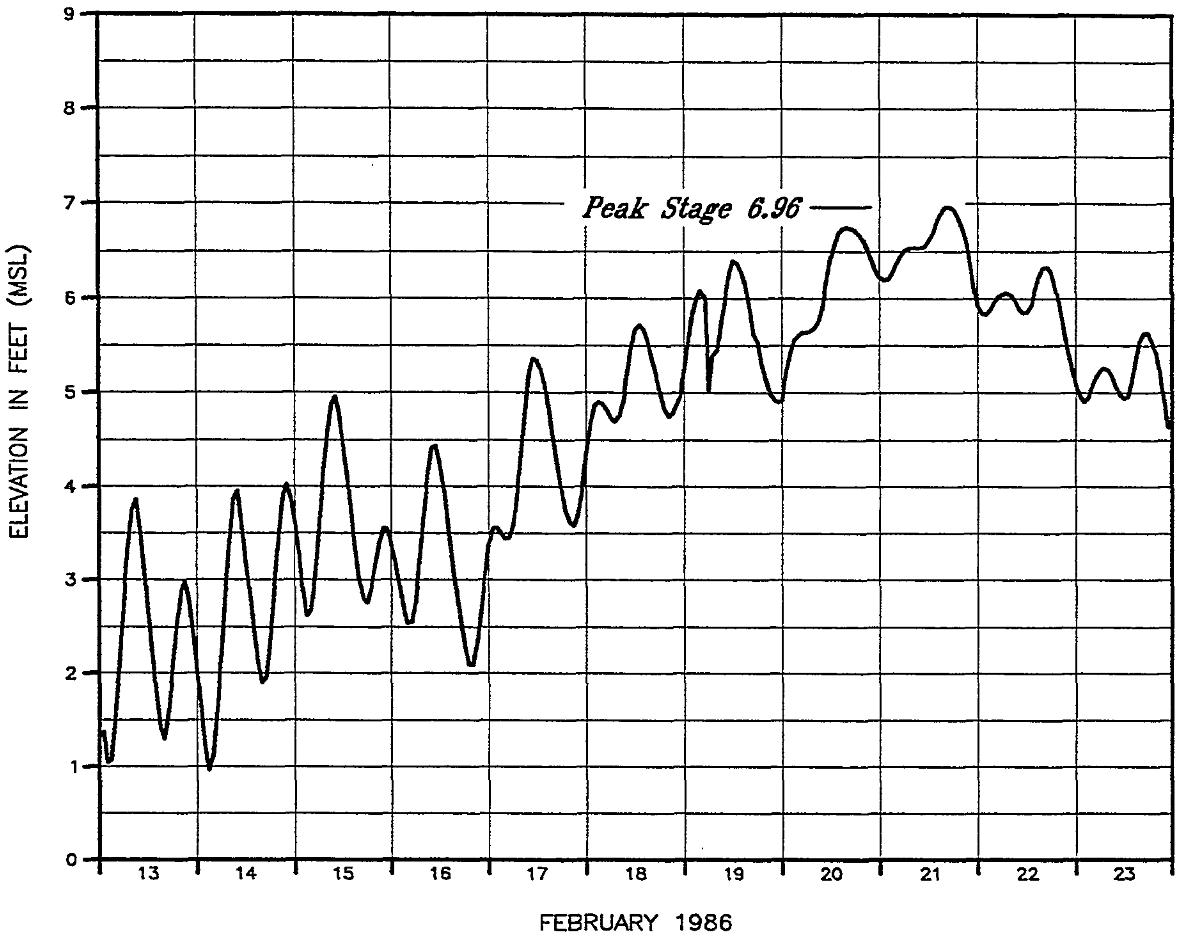
FEBRUARY 1986 FLOOD EVENT
STAGE HYDROGRAPH

YOLO BYPASS
AT RD 2068 PUMP STATION

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 40

C-103420



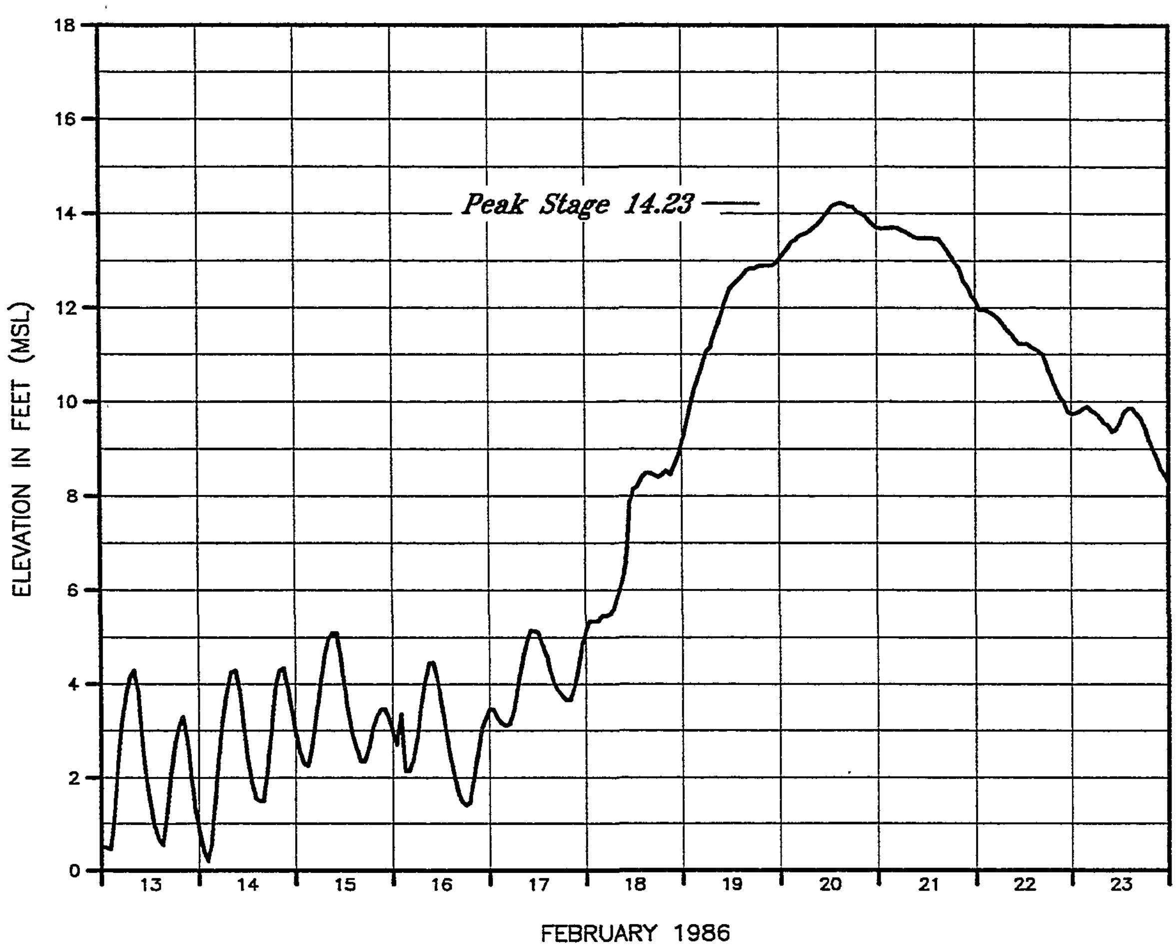
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

FEBRUARY 1986 FLOOD EVENT STAGE HYDROGRAPH

GEORGIANA SLOUGH AT MOKELUMNE RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 41

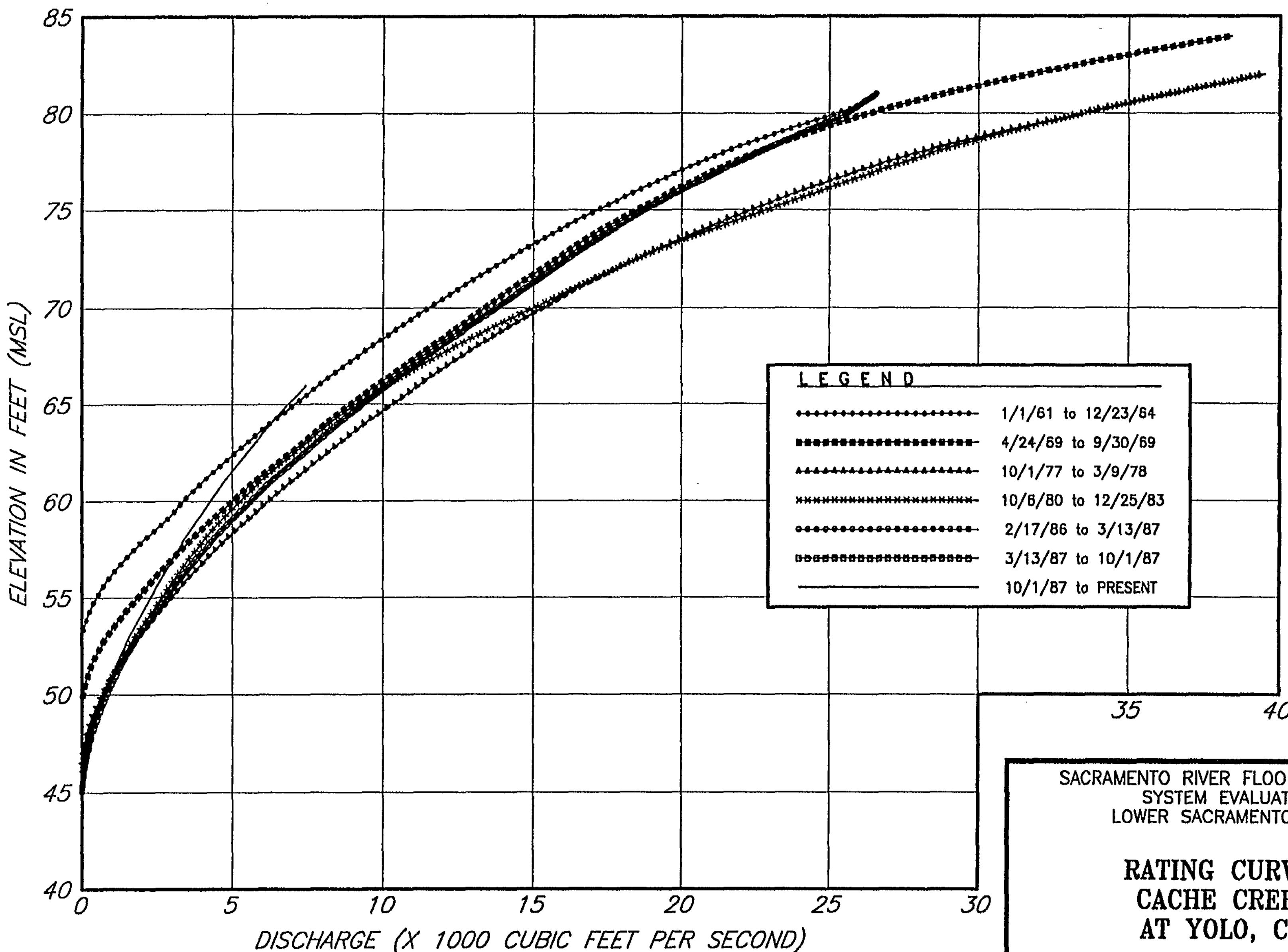


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

FEBRUARY 1986 FLOOD EVENT
STAGE HYDROGRAPH
SACRAMENTO RIVER
DEEP WATER SHIP CHANNEL

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 42



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**RATING CURVES
CACHE CREEK
AT YOLO, CA.**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 43

GEOTECHNICAL

Geotechnical studies on Cache Creek, Willow Slough Bypass, and Putah Creek were done in the Phase III, Mid-Valley Area, Initial Appraisal Report and are detailed there. Roger Foott Associates, Inc., performed geotechnical assessments of the Cache Creek levees, the Willow Slough Bypass levees, and the Putah Creek levees. Geotechnical assessments of these levees are included in the Phase III, Mid-Valley Initial Appraisal Report in Attachment B, "Office Report, Geotechnical Portion of the Initial Appraisal Report for the Sacramento River Flood Control System Evaluation, Mid-Valley Area," July 1990.

Harlan Tait Associates was contracted by the Corps of Engineers, Sacramento District, to provide geotechnical engineering services for the study area. The work effort included subsurface exploration, soil sampling, and stability assessments over 262 miles of project levees (Lower Sacramento River Area project levees excluding Cache Creek, Willow Slough Bypass, and Putah Creek) in Sacramento, Solano, and Yolo Counties.

For the geotechnical program, 245 borings were drilled for the Lower Sacramento River Area project levees with information contained in the 25 April 1990, report by Harlan Tait Associates and the February 1993, "Basis of Design, Geotechnical Evaluation of Levees for the Sacramento River Flood Control System Evaluation, Lower Sacramento River Area, Phase IV" report by the Soil Design Section of the Geotechnical Branch, Corps of Engineers, Sacramento District (see Attachment B). The borings were drilled to depths ranging from 25 to 100 feet below the levee crown and depths ranging from 20 to 50 feet below the levee toe. The above information was also supplemented with boring logs from previous investigations by the Corps of Engineers, other geotechnical firms, and the California Department of Transportation. Soil samples collected from the borings were delivered to the Corps South Pacific Division Laboratory in Sausalito, California, for testing. In addition, soil maps and aerial photographs were reviewed to identify subdued topographic and geologic features, and engineering analyses were performed to evaluate slope stability of the levee embankments and the potential for damage due to seepage and piping. Where levee improvements (or reconstruction) are warranted, recommendations for repair of the levees were made and applicable design concepts developed.

Cross-section information obtained by Harlan Tait Associates indicate levee heights within the study area range from 10 to 30 feet above the landside ground surface. Crowns are from 20 to 60 feet wide. In addition, Harlan Tait Associates encountered wide variations in the levee embankment and foundation soil conditions. These variations occur both between study sites and within individual sites studied (and frequently occur over short vertical and lateral distances). The variable soil types ranged from soft to very stiff clayey silts to clean sand deposits.

The slope stability analysis in the Lower Sacramento Area, Phase IV, was performed in three parts because of the wide range of levee embankment types and foundation conditions. In the first part, a set of chart solutions (detailed in the July 10, 1990, report by Harlan Tait Associates) encompassing the general range of levee embankments and foundations was developed and used to screen each levee reach and to identify the levees which required a more detailed stability assessment. The chart solutions were based on a flood peak 3 to 6 feet below the levee crown, depending on the design freeboard and a steady-state seepage condition. Factors considered included levee embankment height and slope, soil unit weight, shear strength, and depth of tension cracks. The levee embankments with indicated slope stability factors of safety of 1.4 or greater were considered adequate to meet existing Corps requirements. The remaining levee embankments, with indicated factors of safety of less than 1.4, were evaluated in more detail. The second part, also performed by Harlan Tait Associates, evaluated the 90 miles of the southern portion of the study area. In addition to the above factors used in the chart solutions, the detailed evaluation considered site-specific variations in shear strengths (shear strengths were modified to simulate physical changes with depth and location within the levee embankment and foundation) and in the phreatic surface. For the third part, the Corps Soil Design Section of the Geotechnical Branch evaluated the remaining 172 miles of the northern portion of the study area. The Soil Design Section reexamined the second part recommendations and made final recommendations for levee reconstruction in the entire study area.

Results from the geotechnical studies indicate that the primary concern related to levee embankment integrity in the study area is the susceptibility of levee embankment and foundation soils to seepage and piping. Potential problems develop when seepage through permeable levee sections causes saturation of the landside slope. This results in local slumping and progressive failure back into the levee embankment. This condition is most likely with sandy levees having only small percentages of silt and clay particles. The problem is also a function of levee geometry (steep levee embankment slopes and small cross-section widths would increase the potential for this type of damage) and the existence and location of landside drainage ditches.

Potential problems also result from seepage water moving through permeable levee foundation soils. If the energy of the seepage water is great enough, boils (Figure 3) and piping can occur landward of the levee embankment. Seepage evaluations included the determination of levee embankment and foundation characteristics which could lead to the development of seepage problems (information was generally obtained from borings and field surveys), a review of historic problem areas and field observations during high flood stages, and the computation of potential seepage exit gradients (such as in the Initial Appraisal Reports for the Marysville-Yuba City Area, Phase II, and the Mid-Valley Area, Phase III).

Based on the above, geotechnical problem areas along Threemile Slough are mainly caused by a sandy levee embankment and foundation. In general, levee embankments adjacent to channels of the Lower Sacramento River Area were constructed with dredged material from the channel bed; the dredged material contained high percentages of sand particles. A problem area along the lower Sacramento River, Georgiana Slough, and other areas where the majority of foundation soil consists of peat, an organic material, is unique because oxidization of the peat slowly disintegrates the levee foundation and causes the levee to settle.

Geotechnical staff from the Corps of Engineers (Sacramento District) reviewed the reports by Harlan Tait Associates for technical accuracy. In addition, the geotechnical staff prepared a report (see Attachment B) which summarizes information and evaluations of the Phase IV and associated problems. Included in this geotechnical evaluation are the Corps preliminary recommendations for levee reconstruction based on the design water-surface profiles shown in Plates 5 through 19 with a flood peak duration of 3 days. As noted previously, Harlan Tait Associates made its analyses based on a water-surface elevation that was 3 to 6 feet below the existing levee crown, depending on the design freeboard. The 3 to 6 feet of freeboard was used by the consultant because levee crown and design water-surface profiles were not available at that time. In addition, the consultant used variable phreatic surface in the evaluations of slope stability and seepage that generally provided higher factors of safety and design requirements. The types of evaluations made by the Corps in developing recommendations for levee reconstruction are similar to those used in Phases I, II, and III of the Sacramento River Flood Control System Evaluation (see Initial Appraisal Reports for the Sacramento Urban, Marysville/Yuba City, and Mid-Valley Areas).

DESIGN FREEBOARD

As discussed in the Design Water-Surface Profile section, 3 feet is the minimum authorized freeboard required on the Sacramento River and various sloughs in the Delta; 6 feet is the minimum required freeboard on Yolo Bypass to meet design requirements for the flood control project (see Table 2). The freeboard specified for the Sacramento River Flood Control Project levees is the minimum vertical elevation difference required between the design water surface and the levee crown.

Excluding railroad and road crossings and localized depressed areas of the levee embankment crown with flood gates or other means of closure during high flood stages, about 32 miles of levee embankment has deficient design freeboard; in addition, Cache Creek, Willow Slough Bypass, and Putah Creek have about 18 miles of deficient design freeboard. The design freeboard deficiency reaches a maximum of 5 feet, as shown in Table 5. Data suggest that ground-water pumping is likely to have lowered the ground level along Cache Creek, Willow Slough Bypass, and Putah Creek. As indicated by "Levee and Channel Profiles," Corps of Engineers, March 1957, the levee crown profiles had the minimum design freeboard required at that time (1957). A comparison of the 1957 levee crown profiles and those shown on Plates 5 through 19 does indicate significant changes in the locations of grade changes, low sections, and general shape.

Levee raising on the Yolo Bypass right bank is required to meet design elevations in reaches (see Tables 5 and 6) where levee embankments have subsided and slipped in the past. Early reports indicate that portions of the east levee of Yolo Bypass were constructed on tule marshes. It is possible that marsh material in the foundation has consolidated over time, resulting in lower levee crown elevations today. Both sides of Georgiana Slough have a considerable amount of levee height deficiency (15.14 miles), as shown on Plate 12. Some of these areas are underlain by peat deposits which are known to cause the regional subsidence in many locations in the Sacramento-San Joaquin Delta. On the Sacramento River, levee raising to meet design elevations is needed in the north near Freeport and Hood and in the south at Sherman Island.

Figure 44 shows the Lower Sacramento Area flood plain, except for the potential flood plains of Cache Creek, Willow Slough, and Putah Creek. Deficient freeboards of one location could result in an entire island in the Delta being inundated.

For Cache Creek, Willow Slough Bypass, and Putah Creek, maintenance records and field observations do not indicate significant levee embankment problem areas along the study levee reaches (Plates 5 to 7). A few localized areas of channel bank erosion could have resulted in waterside sloughing of the levee embankment slope material in the past. Also, levee embankment slopes in some reaches of Cache Creek and Willow Slough Bypass suggest some minor slippage of the levee embankment.

TABLE 5

LEVEE REACHES WITH
DEFICIENT DESIGN FREEBOARD

Location (channel miles)	Length of Levee Reach [1] (miles)	Design Freeboard Deficiency (feet)
Cache Creek [2]		
5.10 to 5.22 left bank	0.12	0 to 0.6
5.24 to 6.47 left bank	1.23	0 to 3.4
6.50 to 9.57 left bank	3.07	0 to 4.1
5.04 to 6.47 right bank	1.43	0 to 3.1
6.49 to 9.60 right bank	3.11	0 to 3.9
Cache Slough		
2.82 to 2.97 left bank	0.15	0 to 0.8
3.07 to 3.72 left bank	0.65	0 to 1.6
4.11 to 4.15 left bank	0.04	0 to 0.5
4.34 to 4.79 left bank	0.45	0 to 1.6
4.95 to 5.02 left bank	0.07	0 to 0.5
5.18 to 5.92 left bank	0.74	0 to 1.1
0.10 to 0.61 right bank	0.51	0 to 1.0
0.87 to 1.31 right bank	0.44	0 to 0.7
1.37 to 1.71 right bank	0.34	0 to 0.8
Georgiana Slough		
0.00 to 0.29 left bank	0.29	0 to 1.2
0.63 to 0.84 left bank	0.21	0 to 1.0
1.78 to 1.95 left bank	0.17	0 to 0.5
2.36 to 3.19 left bank	0.83	0 to 1.6
3.83 to 4.05 left bank	0.22	0 to 0.5
4.83 to 5.14 left bank	0.31	0 to 0.9
5.91 to 6.15 left bank	0.24	0 to 0.6
6.21 to 6.55 left bank	0.34	0 to 0.4
6.62 to 6.71 left bank	0.09	0 to 0.2
7.64 to 7.79 left bank	0.15	0 to 0.2
8.07 to 8.40 left bank	0.33	0 to 0.6
8.48 to 8.80 left bank	0.32	0 to 0.6
8.84 to 9.34 left bank	0.50	0 to 1.2
9.42 to 9.62 left bank	0.20	0 to 0.7
9.77 to 10.79 left bank	1.02	0 to 1.3
11.03 to 11.20 left bank	0.17	0 to 0.4

Georgiana Slough (cont)		
0.04 to 0.86 right bank	0.82	0 to 3.1
0.92 to 3.86 right bank	2.94	0 to 3.3
4.75 to 4.89 right bank	0.14	0 to 0.6
5.22 to 5.70 right bank	0.48	0 to 1.3
5.72 to 6.73 right bank	1.01	0 to 2.4
6.86 to 8.35 right bank	1.49	0 to 1.7
8.54 to 9.22 right bank	0.68	0 to 1.1
9.74 to 9.95 right bank	0.21	0 to 0.3
10.07 to 10.44 right bank	0.37	0 to 0.6
10.97 to 11.26 right bank	0.29	0 to 0.8
Haas Slough		
1.13 to 1.33 left bank	0.20	0 to 0.7
1.85 to 2.20 left bank	0.35	0 to 0.6
0.08 to 3.50 right bank	2.42	0 to 2.7
Lindsey Slough		
0.29 to 0.39 left bank	0.10	0 to 1.2
0.43 to 0.53 left bank	0.10	0 to 0.8
4.45 to 4.50 left bank	0.05	0 to 0.2
4.63 to 4.66 left bank	0.03	0 to 0.1
Miner Slough		
0.82 to 0.90 right bank	0.08	0 to 1.3
1.45 to 1.47 right bank	0.02	0 to 0.4
Putah Creek [2]		
3.89 to 5.28 left bank	1.39	0 to 1.9
6.22 to 6.67 left bank	0.45	0 to 0.7
6.81 to 7.03 left bank	0.22	0 to 2.6
7.50 to 7.75 left bank	0.25	0 to 0.5
8.06 to 8.15 left bank	0.09	0 to 0.4
3.89 to 3.91 right bank	0.02	0 to 1.5
3.96 to 5.02 right bank	1.06	0 to 1.9
6.10 to 6.84 right bank	0.74	0 to 1.1
6.88 to 6.99 right bank	0.11	0 to 0.3
8.74 to 8.83 right bank	0.09	0 to 1.2
Sacramento River		
3.75 to 3.87 left bank	0.12	0 to 1.1
4.07 to 4.19 left bank	0.12	0 to 1.9
6.55 to 6.57 left bank	0.02	0 to 0.2
38.36 to 38.56 left bank	0.20	0 to 0.9
45.30 to 45.36 left bank	0.06	0 to 0.5
Threemile Slough		
1.00 to 1.05 left bank	0.05	0 to 0.3
1.14 to 1.32 left bank	0.18	0 to 1.6
1.36 to 3.00 left bank	1.64	0 to 3.4

Threemile Slough (cont)		
1.71 to 1.76 right bank	0.05	0 to 0.2
1.84 to 1.96 right bank	0.12	0 to 1.0
2.13 to 2.21 right bank	0.08	0 to 0.2
2.29 to 2.39 right bank	0.10	0 to 0.7
3.32 to 3.78 right bank	0.46	0 to 1.6
Willow Slough Bypass [2]		
3.44 to 6.16 left bank	2.72	0 to 3.1
3.48 to 3.93 right bank	0.45	0 to 0.7
4.04 to 6.16 right bank	2.12	0 to 2.9
Yolo Bypass		
17.93 to 18.20 right bank	0.27	0 to 0.9
18.40 to 18.55 right bank	0.15	0 to 2.1
18.70 to 19.60 right bank	0.90	0 to 4.6
21.20 to 21.97 right bank	0.77	0 to 1.4
22.00 to 24.49 right bank	2.49	0 to 2.4
24.65 to 25.75 right bank	1.10	0 to 2.1
25.95 to 26.57 right bank	1.02	0 to 0.6
26.59 to 27.43 right bank	0.84	0 to 0.7
27.56 to 30.44 right bank	2.29	0 to 1.6

[1] Levee reach miles are measured along the centerline of the levee embankment crown and do not necessarily correspond to the difference indicated by the channel mile locations.

[2] No Federal interest at this time due to possible non-design defects.

TABLE 6

PROPOSED LEVEE RAISING AND GEOTECHNICAL REPAIRS

Location (Channel Miles)	Proposed Repairs: Levee Raising maximum (feet)	Proposed Repairs: Geotechnical Repairs
Cache Slough*		
0.10 to 0.61 R	1.0	--
0.87 to 1.31 R	1.0	--
1.37 to 1.71 R	1.0	--
2.41 to 2.81 L	--	Restore lower portion of L/S slope
2.82 to 2.97 L	0.8	--
3.07 to 3.72 L	1.7	--
4.11 to 4.15 L	0.5	--
4.34 to 4.79 L	2.0	--
4.95 to 5.02 L	0.7	--
5.18 to 5.92 L	1.1	--
15.82 to 16.05 L+	--	Seepage/stability berm, 1,200'
Elk Slough*		
0.90 to 1.00 L	--	Install drainage system, 500'
1.38 to 1.59 L	--	Install drainage system, 1,100'
Georgiana Slough++		
0.00 to 0.29 L	1.0	--
0.60 to 0.63 L	--	Relocate irrigation ditch
0.63 to 0.84 L	1.0	Relocate irrigation ditch
0.87 to 1.50 L	--	Relocate irrigation ditch
1.78 to 1.95 L	0.5	--
2.36 to 2.80 L	1.7	--
2.80 to 3.19 L	1.7	Reconstruct L/S slope
3.19 to 3.20 L	--	Reconstruct L/S slope
3.83 to 4.05 L	0.7	--
4.20 to 4.40 L	--	Seepage berm or slurry cutoff wall, 1,000'
4.83 to 5.14 L	1.0	--
5.91 to 6.15 L	0.6	--
6.21 to 6.55 L	0.5	--
6.62 to 6.71 L	0.5	--
7.64 to 7.79 L	0.2	--
8.07 to 8.40 L	0.7	--
8.43 to 9.61 L	1.2	--
9.77 to 10.79 L	1.6	--
11.03 to 11.20 L	0.5	--
0.04 to 1.50 R	3.3	--
1.50 to 3.81 R	3.3	Stability berm
3.81 to 3.86 R	--	Stability berm
4.75 to 4.89 R	0.8	--

5.22 to 5.65 R	2.0	--
5.65 to 5.75 R	2.0	Backfill borrow excavation pit L/S toe, 100', or L/S berm with slurry cutoff wall, 1,000'
5.75 to 6.73 R	2.0	--
6.86 to 6.88 R	--	Backfill irrigation ditch & construct seepage berm
6.88 to 8.20 R	2.0	Backfill irrigation ditch & construct seepage berm
8.20 to 8.35 R	2.0	--
8.54 to 9.22 R	1.1	--
9.74 to 9.95 R	0.5	--
10.07 to 10.44 R	1.0	--
10.97 to 11.26 R	1.0	--
Haas Slough*		
0.04 to 0.22 L	--	Backfill irrigation ditch, 400'
1.13 to 1.33 L	0.7	--
1.85 to 2.20 L	0.6	--
0.08 to 3.50 R	2.7	--
Lindsey Slough*		
0.29 to 0.39 L	1.2	--
0.43 to 0.53 L	1.0	--
4.45 to 4.50 L	0.2	--
4.63 to 4.66 L	0.1	--
Miner Slough*		
0.82 to 0.90 R	1.3	--
1.45 to 1.47 R	1.5	--
Sacramento River++		
3.75 to 3.87 L	1.3	--
4.07 to 4.19 L	2.0	--
6.55 to 6.57 R	0.2	--
37.53 to 38.36 L	--	Seepage/stability berm
38.36 to 38.56 L	1.0	Seepage/stability berm
38.56 to 39.73 L	--	Seepage/stability berm
41.44 to 41.82 L	--	Seepage/stability berm, 2,000'
43.54 to 44.90 L	--	Seepage/stability berm, 7,200'
45.37 to 45.53 L	0.8	--
Steamboat Slough++		
16.18 to 16.65 R	--	Seepage/stability berm, 2,500'
19.35 to 19.73 R	--	Seepage/stability berm, 2,000'
22.10 to STSI R	--	Stability berm, 1,500'
21.12 to 21.17 L	--	Backfill ditch & sinkhole, 300'
24.45 to 26.06 L	--	Stability berm or slurry cutoff wall, 8,000'
Sutter Slough++		
21.88 to STSI L	--	Stability berm, 1,500'

Threemile Slough++		
1.00 to 1.14 L	--	Seepage/stability berm
1.14 to 1.32 L	1.8	Seepage/stability berm
1.32 to 1.36 L	--	Seepage/stability berm
1.36 to 1.78 L	3.5	Seepage/stability berm
1.78 to 1.90 L	--	Seepage/stability berm
1.90 to 3.00 L	3.5	Seepage/stability berm
1.71 to 1.76 R	1.0	--
1.84 to 1.96 R	1.1	--
2.13 to 2.21 R	1.0	--
2.29 to 2.39 R	0.7	--
3.32 to 3.78 R	1.8	--
Yolo Bypass++		
17.93 to 18.20 R	1.0	--
18.40 to 18.55 R	2.1	--
18.70 to 19.60 R	5.0	--
22.00 to 23.04 R	2.3	--
23.04 to 24.04 R	2.3	Restore levee slopes
24.04 to 24.14 R	2.3	Restore levee slopes
24.14 to 24.65 R	2.3	Restore levee slopes
24.65 to 27.74 R	2.3	Restore levee slopes
24.74 to 24.84 R	2.3	--
24.84 to 25.17 R	2.3	Restore levee slopes
25.17 to 25.36 R	--	Restore levee slopes
25.36 to 25.48 R	1.0	Restore levee slopes
25.48 to 25.51 R	--	Restore levee slopes
25.51 to 25.54 R	2.0	Restore levee slopes
25.54 to 25.75 R	2.0	--
25.75 to 26.48 R	2.0	Restore L/S berm
26.48 to 26.59 R	--	Restore L/S berm
26.59 to 27.46 R	1.0	Restore L/S berm
27.46 to 27.54 R	1.0	Restore L/S berm
27.54 to 27.64 R	1.0	--
27.64 to 28.14 R	1.0	Restore L/S berm
28.30 to 30.44 R	2.0	--

Notes:

L = Left bank

R = Right bank

L/S = Landside

STSI = Southern tip of Sutter Island. The geotechnical repair covers parts of Steamboat and Sutter Slough.

* = Levee District channel miles (own reference).

+ = Reference from topographic maps; the proposed geotechnical repair is farther south than other proposed Cache Slough repairs.

++ = Reference from topographic maps.

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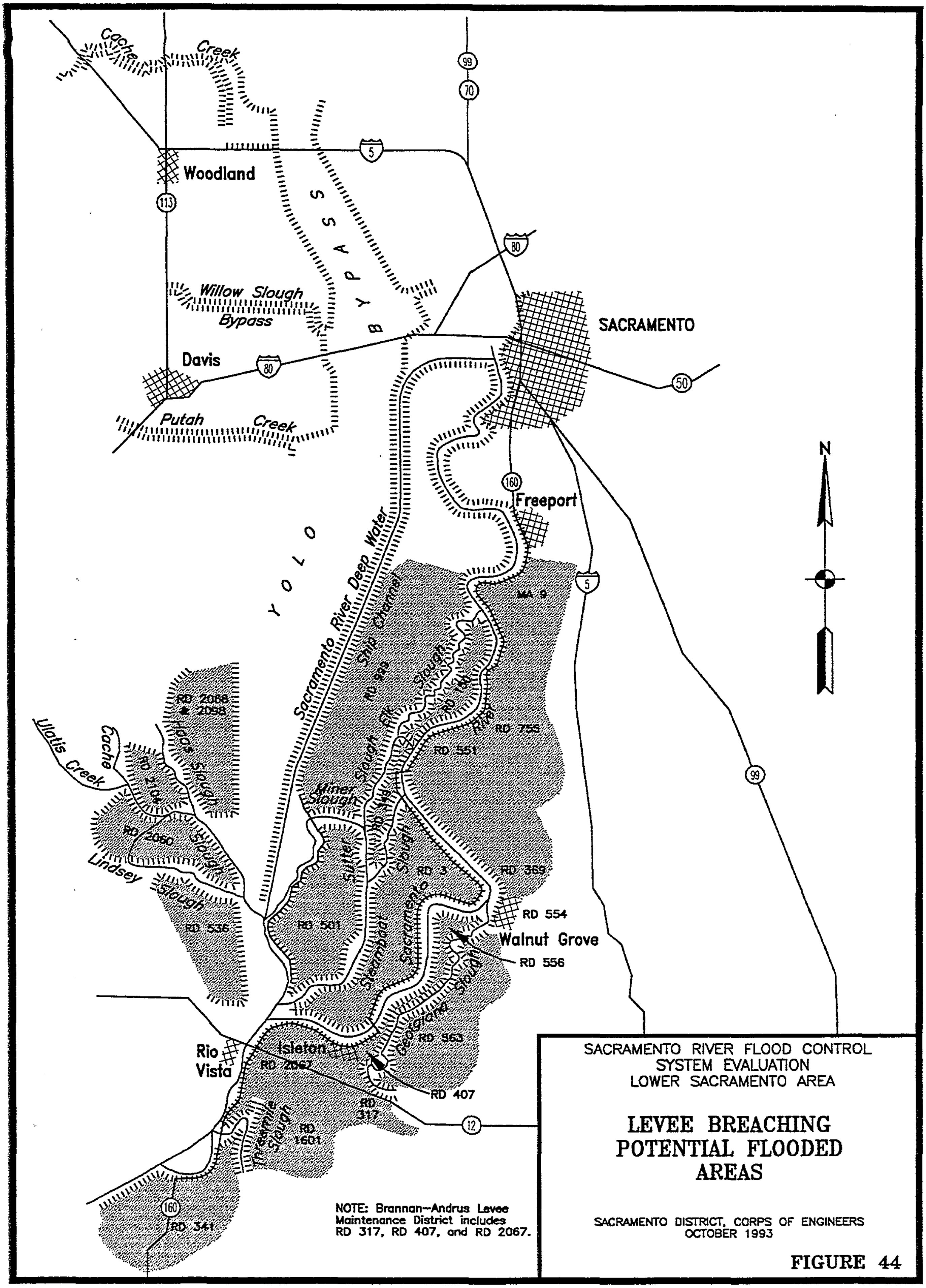


SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE BREACHING POTENTIAL FLOODED AREAS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 44

Recent studies of subsidence in the Sacramento Valley by the U.S. Geological Survey (USGS) and other agencies indicate ground-water pumping is responsible for subsidence in the Cache Creek area. As part of its water transfer studies for the State Water Project, the Department of Water Resources is studying land subsidence in Yolo County from Fremont Weir to Putah Creek. An extensometer at Zamora used in studies by USGS and DWR showed 0.8 foot of subsidence between 1988 and 1992 at a location 2 miles north of Cache Creek (see Figure 45). The extensometer shows an excellent match between ground-water pumping and subsidence. Another extensometer at Conaway Ranch, adjacent to the Yolo Bypass, shows no net subsidence from 1988 to 1992 (see Figure 46 for 1992 readings).

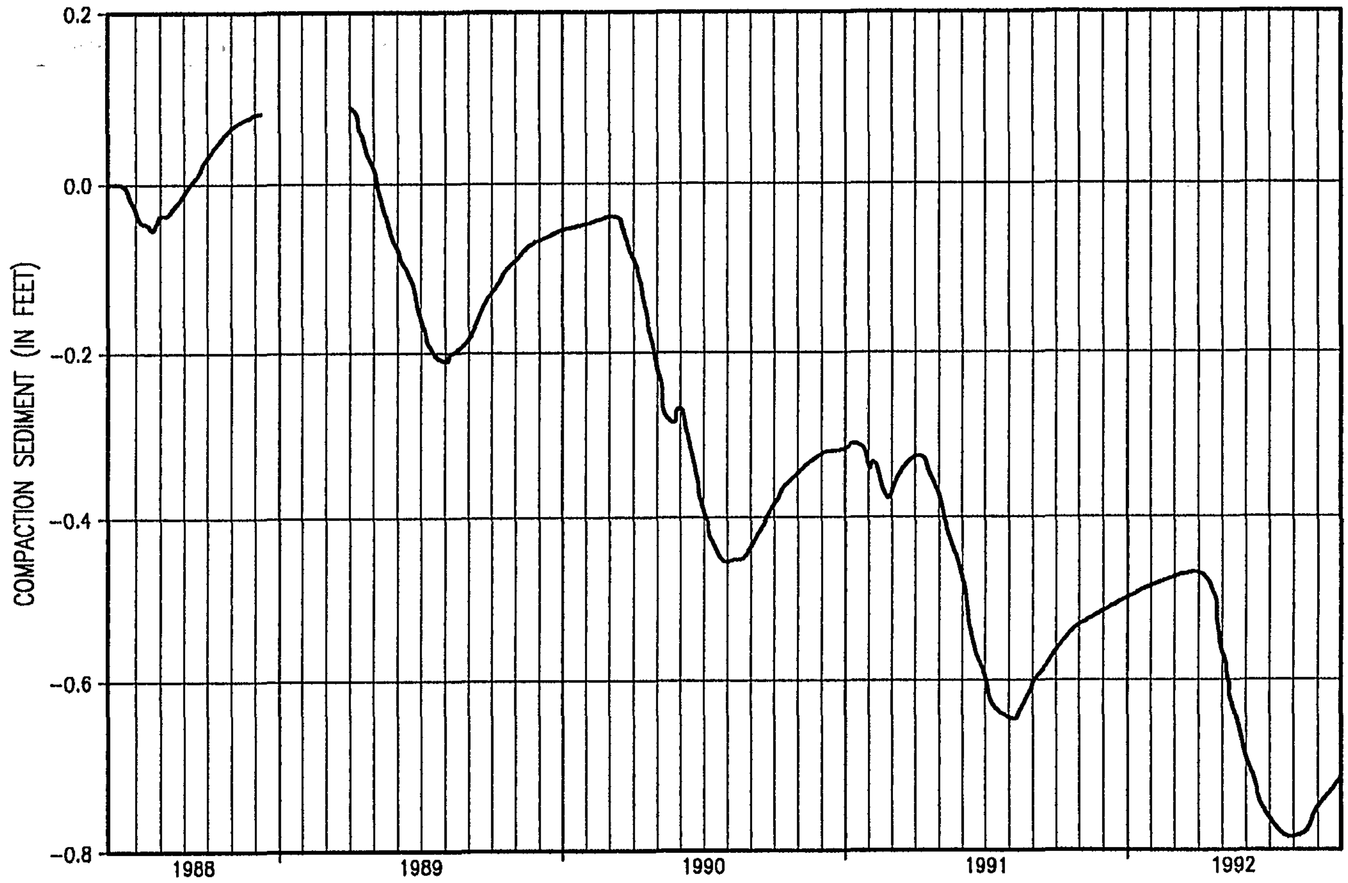
The Corps of Engineers geotechnical staff inspected the levees on Cache Creek, Willow Slough Bypass, and Putah Creek, but did not find any foundation problems. The Corps studies show levee crowns below design water surface and freeboard based on 1957 design water-surface profiles. Validity of the levee crown survey data is in question, as the bench marks are also subsiding. The Corps has no authority to raise levees under the Sacramento River Flood Control System Evaluation if the levee subsidence was not caused by a design deficiency.

DESIGN FLOW

Figure 47 shows the areas where the design flow could not be conveyed within the design water surface during the February 1986 flood. The design flow could not be conveyed within the design water surface in the Yolo Bypass from approximately mile 39 (covered in the Mid-Valley Area, Phase III) to approximately mile 29, miles 19.75 to 19.25, and miles 14.5 to 17. Design flow deficiencies in the Yolo Bypass below the Interstate 80 bridge over Yolo Bypass were identified in the "Initial Appraisal Report, Mid-Valley Area," December 1991. Also, the Willow Slough Bypass Miles 0 through 4 could not convey the design flow, and water was observed to within 1 foot of the top of the Willow Slough Bypass.

The design flow could not be conveyed in portions of the Yolo Bypass in the study area due to possible aggradation of material as discussed in the Mid-Valley, Phase III, Initial Appraisal Report. It is also possible that the construction of the Sacramento River Deep Water Ship Channel and the west levee of the ship channel (also the east levee of the Yolo Bypass) reduced the conveyance capacity in some areas.

Since the 1986 flood, the California Department of Water Resources has removed material from the Yolo Bypass at Fremont Weir (1986, 1987, and 1991) and converted 138 acres of formerly

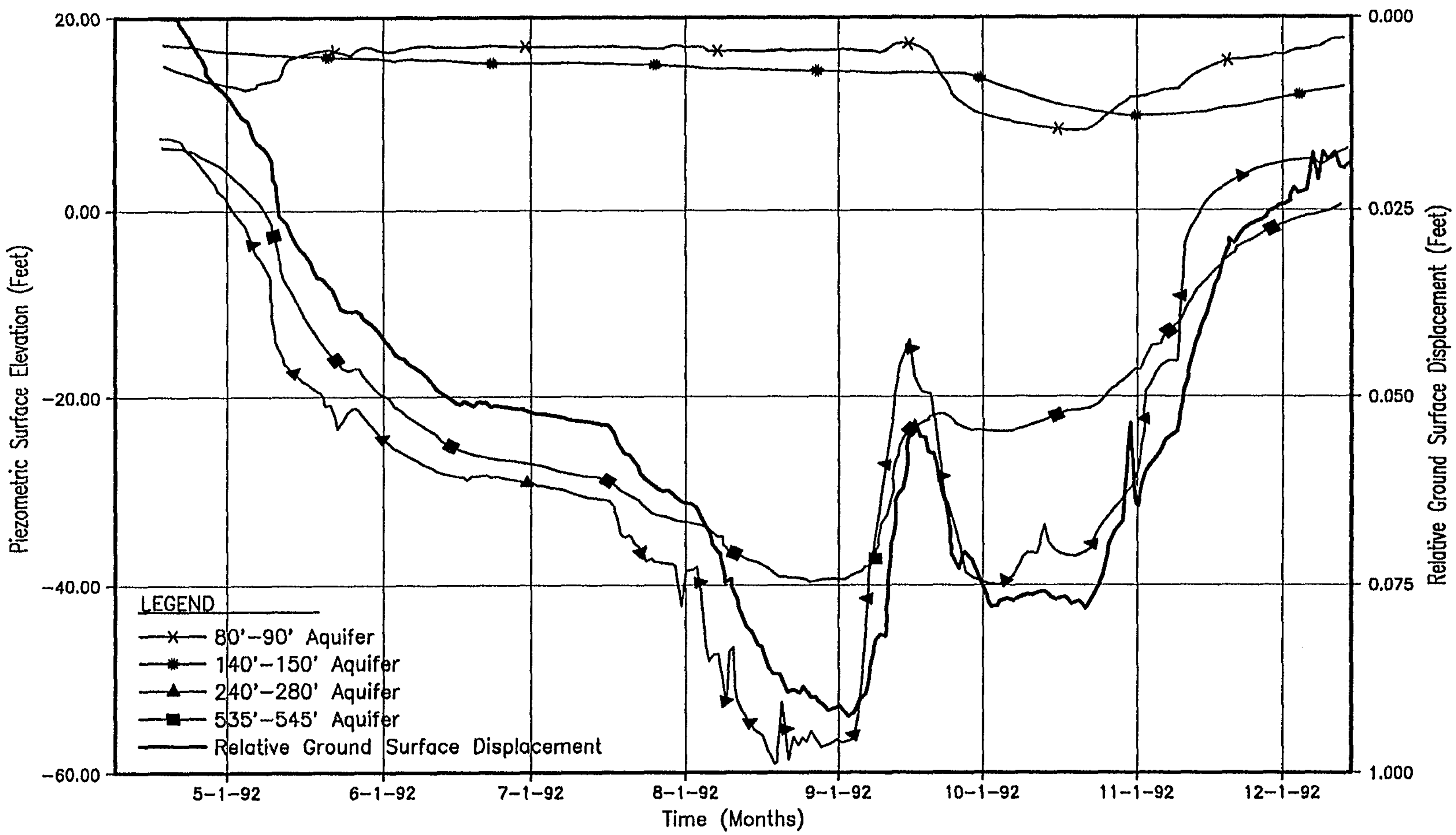


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

NET COMPACTION SEDIMENT AND STEVENS CHART VALUES ZAMORA, CA

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 45

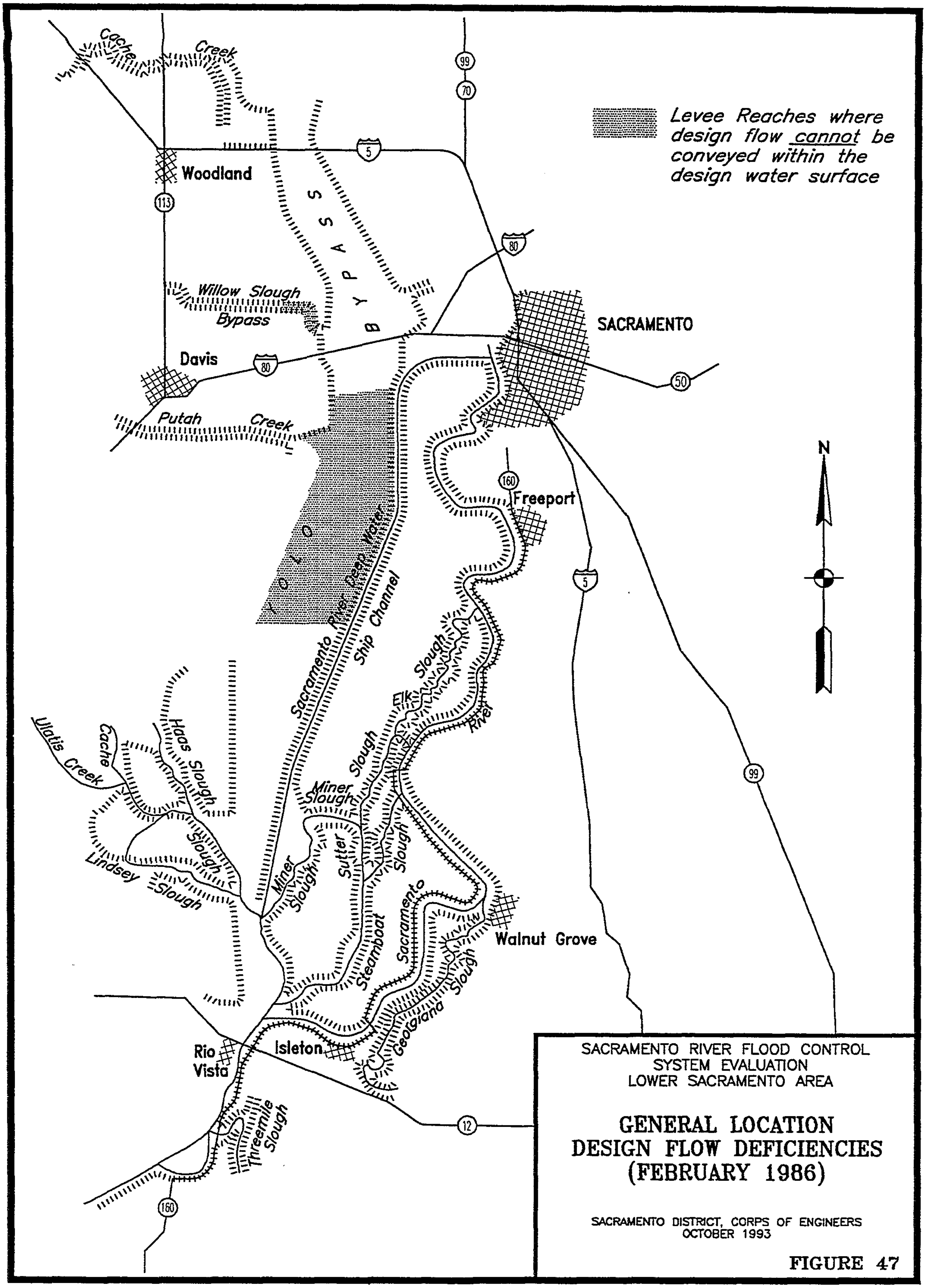


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

ELEVATION OF PIEZOMETER AND RELATIVE GROUND SURFACE DISPLACEMENT, CONAWAY RANCH EXTENSOMETER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 46



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

GENERAL LOCATION
DESIGN FLOW DEFICIENCIES
(FEBRUARY 1986)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 47

leveed agricultural land to open water mitigation at the confluence of Cache Slough and Shag Slough. At this time it is unknown how this will affect present flow conveyance capacity.

The design flow that could not be conveyed on the Willow Slough Bypass may be due to backwater effects from the raised water-surface elevations in the Yolo Bypass, as discussed above.

LEVELS OF FLOOD PROTECTION

Levels of flood protection provided by a levee embankment are difficult to estimate. The physical condition of a levee can change with time based on past forces acting on the embankment. Floods can alter surface and subsurface conditions because of erosion, seepage, and piping. Maintenance practices can alter surface conditions. Development and agricultural practices can modify adjacent land surface and subsurface conditions. Other factors, such as wave action, erosion of the waterside slope, levee embankment erosion, and rodent activity, can also modify the existing condition of the levee embankment.

Problems with levee embankments in prior floods are discussed in the section on Historic Levee Embankment Problem Areas (see Plate 3 also). Some discussion of problem areas may also be found as part of Attachment B, the geotechnical office report. Because of the difficulties of accurately predicting when, where, and under what conditions levee embankment problem areas will occur, levels of flood protection are estimated on the extent and relative significance of hydraulic and geotechnical considerations. Only levee embankment problem areas that have not been modified or repaired since 1986 were considered.

Table 7 shows the estimated recurrence intervals for the February 1986 high-water mark profile for the levee reaches covered by this report. Based on an evaluation of the levee embankment problem areas, freeboard, and geotechnical considerations, levee breaks are expected for the following:

(1) Flood events with peak flood stages similar to the February 1986 flood event, but with slightly longer durations.

(2) Flood events with peak flood stages slightly higher than the February 1986 flood event, but with similar durations.

During the February 1986 flood, seepage, sinkholes, sloughing, and boils were documented at a number of sites in the study area. Boils were sandbagged at a right bank site at Georgiana Slough, Mile 5.6, adjacent to a wetland area created by an old railroad embankment borrow site. It is possible that this area may have failed if flood fight efforts had not been

TABLE 7

RECURRENCE INTERVALS
FOR
FEBRUARY 1986 PEAK FLOOD STAGES

LOCATION	RECURRENCE INTERVAL (YEARS)
Cache Creek (at Yolo)	6 [1]
Elk Slough at Sutter Slough	80
Georgiana Slough at Mokelumne River	20
Haas Slough	
at Bunker Station Road	60
at Cache Creek	60
Miner Slough at Cache Slough	65
Sacramento River	
at I-Street Bridge	70
at Freeport	70
at Elk Slough	70
at Snodgrass Slough	20
at Sutter Slough	80
at Steamboat Slough	70
at Walnut Grove	70
at Rio Vista	70
at Threemile Slough	65
at Collinsville	10
Steamboat Slough at Cache Slough	80
Sutter Slough	
at Miner Slough	60
at Steamboat Slough	80
Threemile Slough at San Joaquin River	2
Ulatis Creek at Cache Slough	60
Yolo Bypass	
near Lisbon (channel mile 35.3)	65
at RD 2068 pump station	100
at Cache Slough	90
at Lindsey Slough	60

[1] Reliability in question due to subsidence and degradation.

initiated. Sites along Georgiana Slough, the Sacramento River, Miner Slough, Cache Slough, Sutter Slough, and Steamboat Slough also exhibited seepage and sand boils during the 1986 flood event.

Although flood fight efforts can and have prevented levee failures in the past, such efforts cannot be depended on during major floods. In this evaluation, flood fight efforts are assumed ineffective in increasing the levels of flood protection. Railroad and road crossings and localized depressed areas of levee embankment crowns with flood gates or other means of closure during high flood stages, though, are assumed to be functional in this analysis when determining levels of flood protection.

The Reclamation Board and local reclamation districts have done some reconstruction work to restore the stability and geotechnical soundness of some of the historic levee embankments at problem areas. Much of this work is detailed in Attachment B, the geotechnical office report. Based on an analysis of these repairs and the assumption of adequate future maintenance, it is reasonable to assume that the repaired study area levees would not fail at peak flood stages and durations less than those of the February 1986 flood.

During high water in the 1992 to 1993 flood season, seepage was apparent at a few sites along Georgiana Slough, Cache Slough, and Threemile Slough. Several sites exhibited some small amount of fines being carried with the seepage (sand boils). Deterioration of the levees can be expected to continue due to geotechnical instabilities in the foundation and levee embankment material unless restoration work is performed.

Soil samples taken of the levee embankment and foundation at and near current problem area locations for proposed geotechnical restoration (see Plate 4) indicate existing factors of safety are less than recommended for design of levee embankments at flood levels equal to or greater than the design water surface. Based on analyses, geotechnical studies, past performance, and geotechnical judgment, the potential for failure is high for flood levels equal to or greater than those of the February 1986 flood.

Levee crown surveys, February 1986 high-water marks, and design water-surface elevations were used to determine where levee raising is required to restore the project levees to authorized heights necessary to safely pass the design stages. Levee crown elevations need to be raised along portions of Georgiana Slough, the Sacramento River, Threemile Slough, Yolo Bypass, Lindsey Slough, Shag Slough, Cache Slough, Sutter Slough, and Haas Slough. Some of the levee crown deficiency is due to geotechnical problems related to levee material and foundations.

On the west side tributaries of the Yolo Bypass, Cache Creek, Willow Slough Bypass, and Putah Creek have levee crown deficiencies which do not appear to be due to geotechnical problems, but are most likely caused by subsidence due to ground-water withdrawal. The levee crown deficiencies on Cache Creek, Willow Slough Bypass, and Putah Creek are not recommended for repair as part of this study, but are recommended for levee crown restoration as part of the operations and maintenance responsibilities of the local sponsor, since the deficiencies appear to be induced by activities under control of the State of California.

Based on the information presented in this section, the 1986 high-water mark profile (static water surface plus wind setup) will be used as the reference water-surface elevation at which piping and structural instability problems would be expected at the proposed levee reconstruction locations shown on Plate 4. Table 7 shows the recurrence intervals for these water-surface elevations for specific locations. The recurrence intervals represent existing conditions and assume no levee breaching within or adjacent to the study area. If levee breaching does occur, either within or adjacent to the study area, the recurrence intervals specified in Table 7 would be increased accordingly to accomplish the economic analysis.

ECONOMICS

Existing levels of flood protection were developed for the study area based on engineering and geotechnical considerations and assuming no upstream levee breaks. The recurrence intervals associated with the 1986 peak flood stages are shown in Table 7 for specific locations within the study area. In general, peak flows equal to or higher than those shown in Table 7 could result in levee failure under current conditions, especially in areas identified as problem areas during the February 1986 flood. During high water in the fall and winter of 1992, seepage and some piping were noted at levels much below the 1986 peak flows in some levees in the study area. Although Federal project levees have not failed in the Lower Sacramento Area (except for Cache Creek in the 1940's and 1983), problems are such that, without reconstruction, the Federal project levees are likely to fail during some future flood below project design.

Within the study area, at least 19 distinct and separate areas could fail and flood independently, excluding levees along Cache Creek, Willow Slough Bypass, and Putah Creek, which are not recommended for restoration because of the likelihood that levee crown deficiencies are due to ground-water removal. The 19 areas are shown in Attachment D, the Economic Evaluation. Of these areas, 13 have levee design deficiencies which are identified in this report. Flood plains are shown in Figure 44.

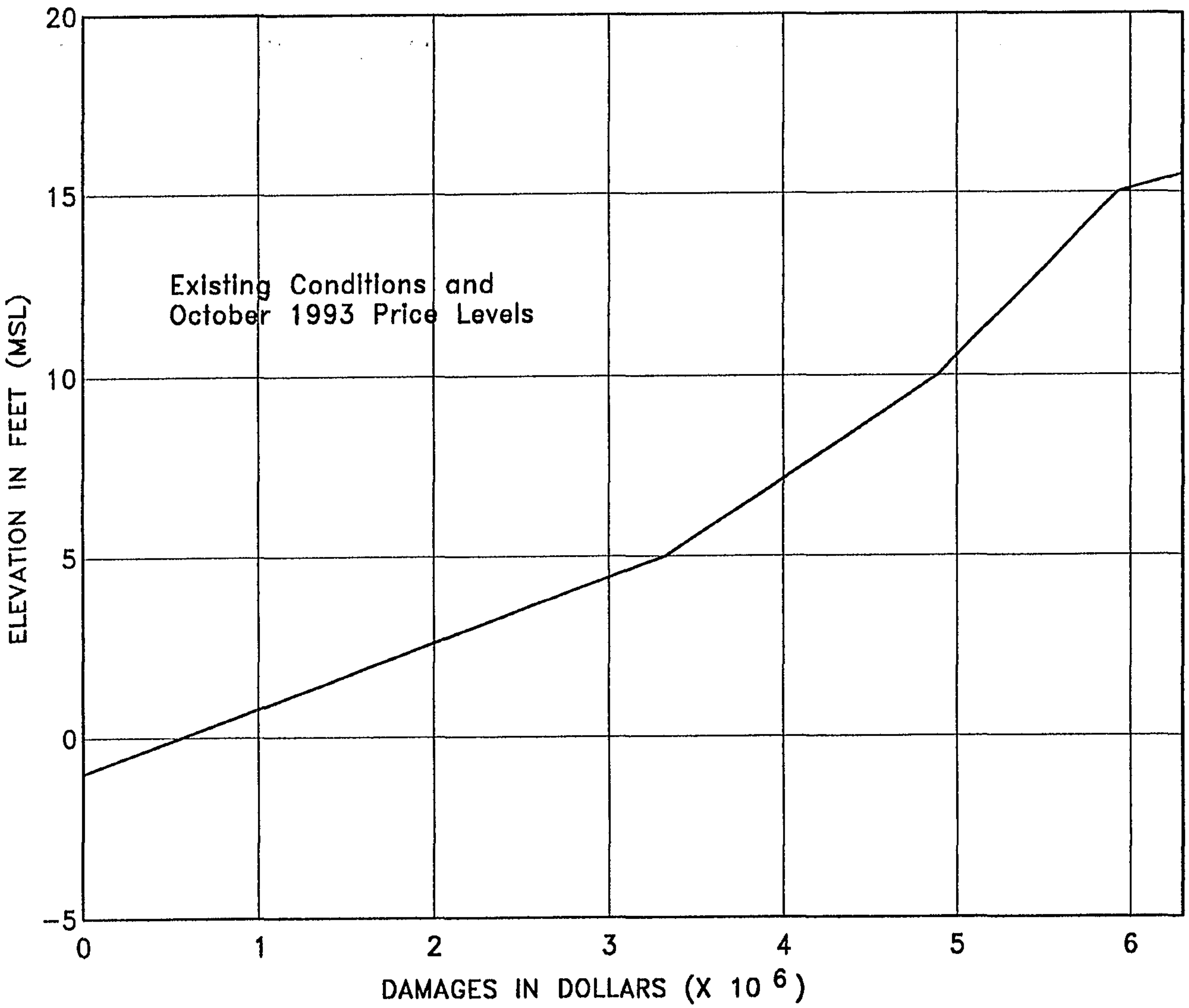
Each of the 19 individual areas was inventoried from aerial photographs and field surveys to determine the number and types of structures, agricultural crops (in particular rice crops) and practices, highways, railroads, and other facilities. The maximum potential flood plain was determined based on Federal and non-Federal levees and design flood elevations. The potential flooded areas in Figure 44 are primarily agricultural, with many of the Delta islands at or below sea level. The Economic Evaluation, Attachment D, presents inventories on each incrementally independent floodable area. Urban areas include the town of Isleton on Brannan-Andrus Island, Hood in Maintenance Area 9, and Clarksburg in The Big Area.

Because of the uncertainty of when, where, and how many levee breaks will occur within, adjacent to, and upstream of the study area, it is assumed in the analysis of this report that there will be no upstream levee breaks. The Corps and The Reclamation Board have repaired a number of deficiencies identified in the Sacramento River Flood Control Project and will continue to correct deficiencies to prevent failures. Repairs to correct deficiencies found in Phase I for the Sacramento Urban Area have already been completed; Phase II for the Marysville/ Yuba City Area is in the pre-construction phase; and Phase III for the Mid-Valley Area is in the Design Memorandum phase.

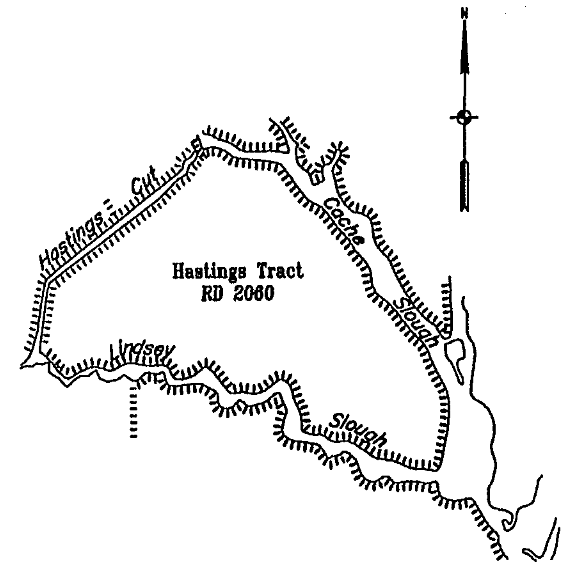
Damage versus elevation relationships are shown on Figures 48 through 66. The relationships of Figures 48 through 66 indicate, as a limit, maximum potential flood damages for each of the individual flooded areas shown on Figure 44. Damages include the cost to repair a levee break as well as the cost to dewater the inundated area. Costs are based on repairs of 1986 levee breaks on the Yuba River and Yankee Slough. Inundation durations of 60 days were used, although longer durations of flooding are possible. Longer durations did not have a significant impact on estimated damages. In the Sacramento Delta, many of the islands protected by levees are below sea level, especially Sherman, Twitchell, Brannan-Andrus, and Tyler Islands. Table 8 displays area, maximum damages, and elevation of maximum damages.

No reconstruction has been identified in RD 2060 (Hastings Tract northwest of Hastings Cut), Figure 49, and (west of Hastings Cut) Figure 50; RD 554 (Tyler Island), north of Route J11, Figure 60; MA 9 (Hood to Snodgrass Slough), Figure 64; and RD 551 (Courtland area), Figure 65.

The maximum potential flood damages cited above suggest difficulty in incrementally justifying the proposed levee reconstruction shown in Plate 4. In addition, the relatively high levels of flood protection specified in Table 7 for the study area (assuming no upstream levee breaching) limit the magnitude of the probability intervals over which average annual benefits can be rationalized. Because of these conditions, a



NOTE: Damages include the cost of repairing one levee break and dewatering.



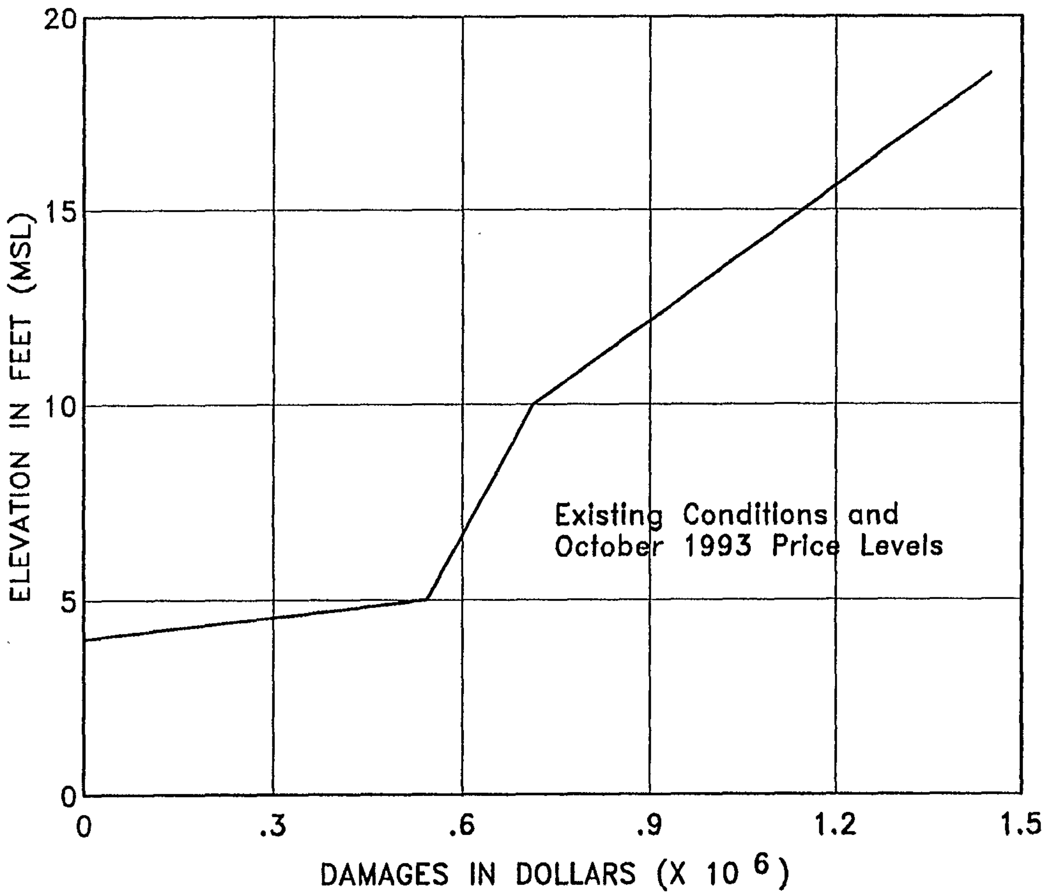
GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

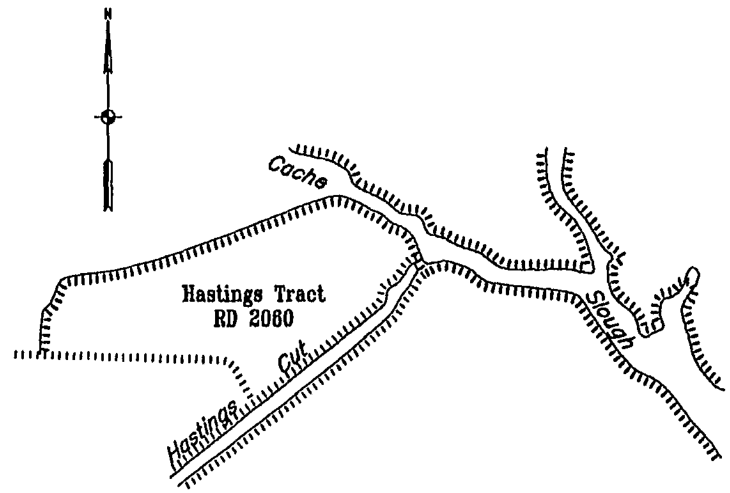
DAMAGES VS. ELEVATION
RD 2060 (HASTINGS TRACT)
(SOUTHEAST OF HASTINGS CUT)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 48



NOTE: Damages include the cost of repairing one levee break and dewatering.



GENERAL LOCATION MAP

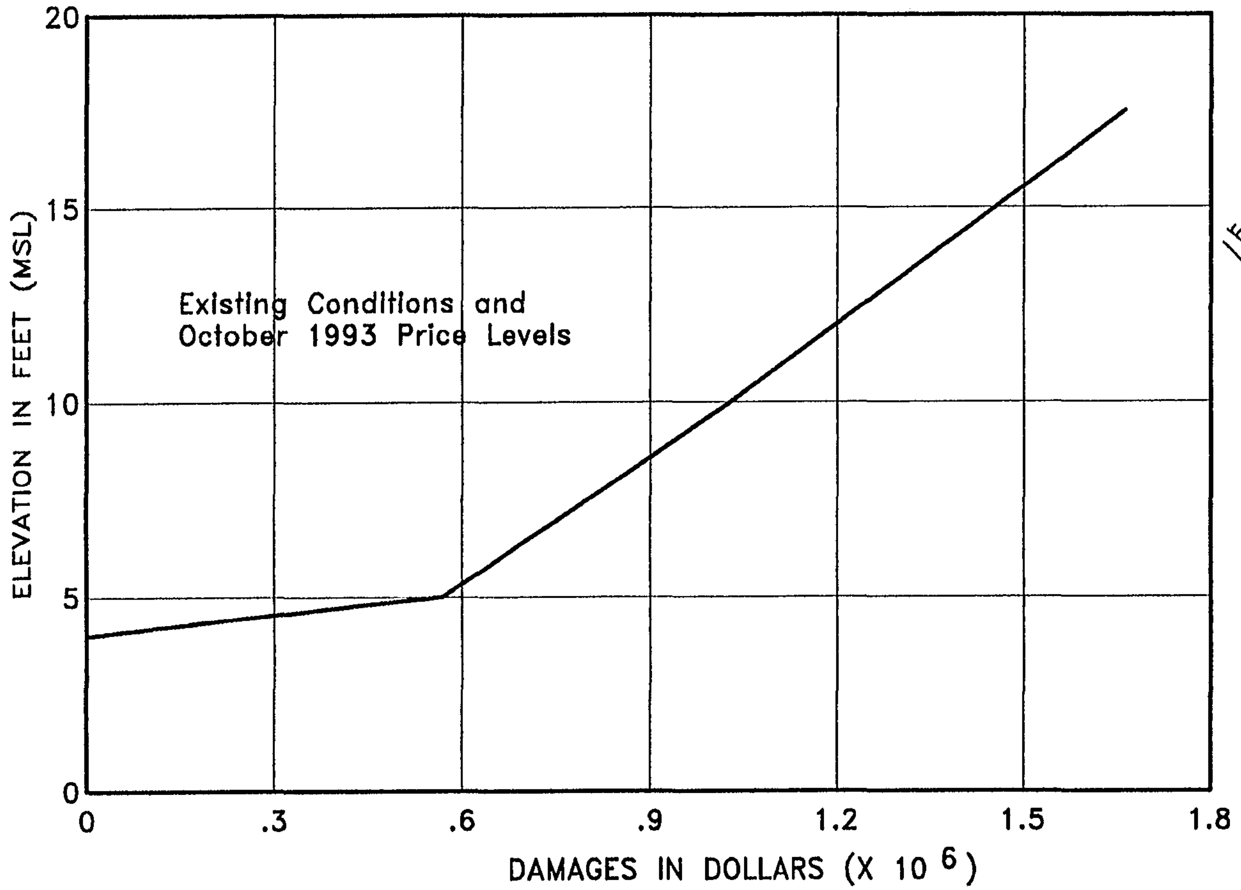
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

**DAMAGES VS. ELEVATION
RD 2060 (HASTINGS TRACT)
(NORTHWEST OF HASTINGS
CUT)**

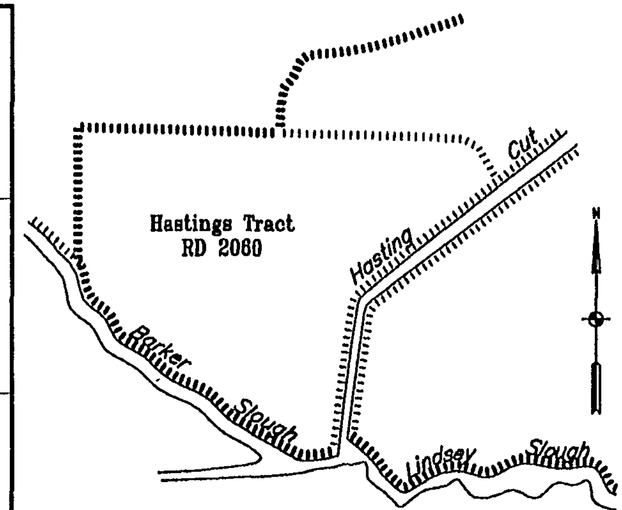
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 49

C-103445



NOTE: Damages include the cost of repairing one levee break and dewatering.



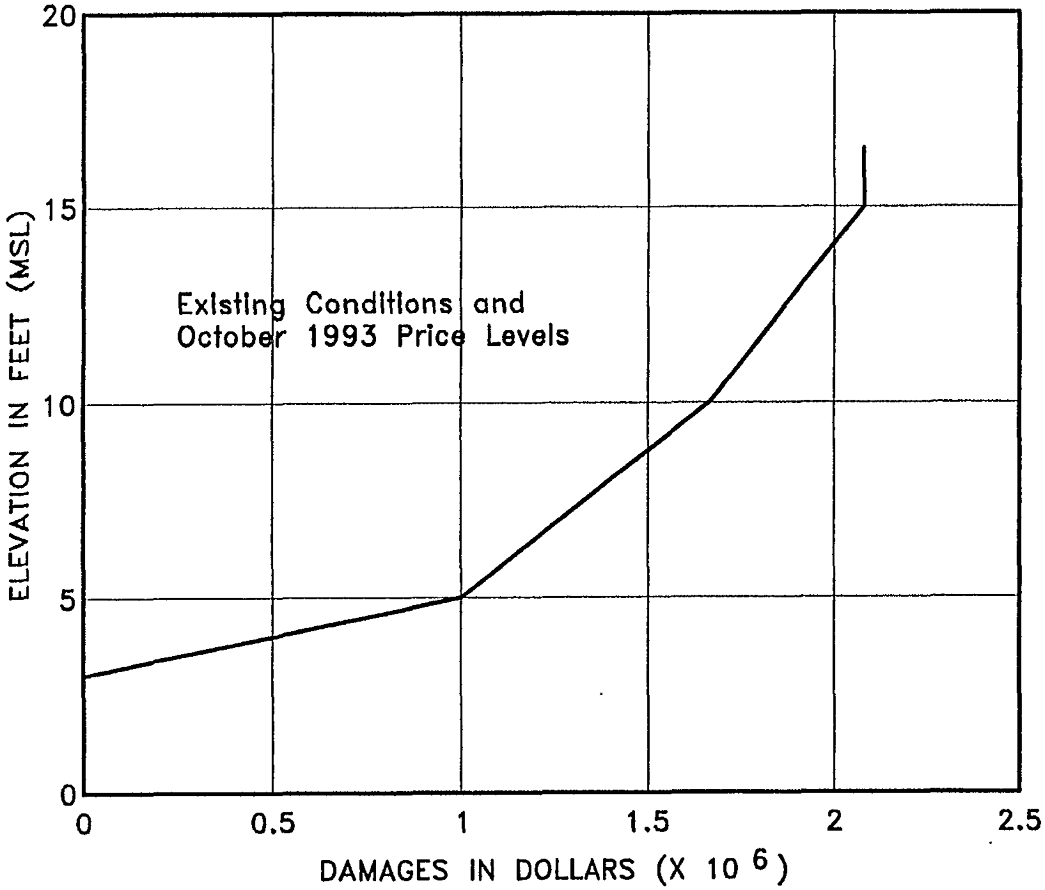
GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

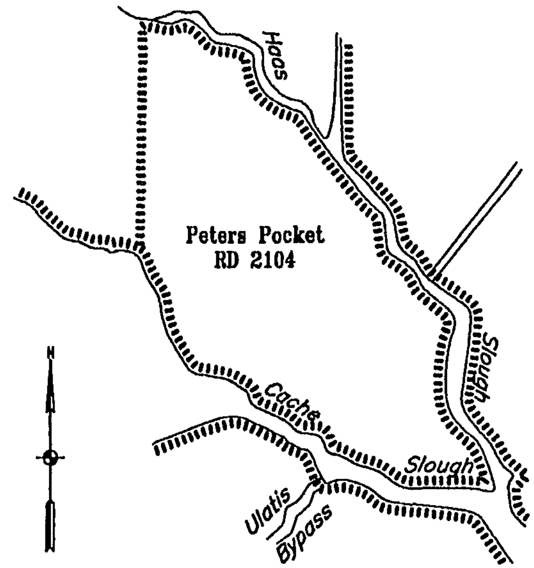
DAMAGES VS. ELEVATION
RD 2060 (HASTINGS TRACT)
(WEST OF HASTINGS CUT)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 50



NOTE: Damages include the cost of repairing one levee break and dewatering.



GENERAL LOCATION MAP

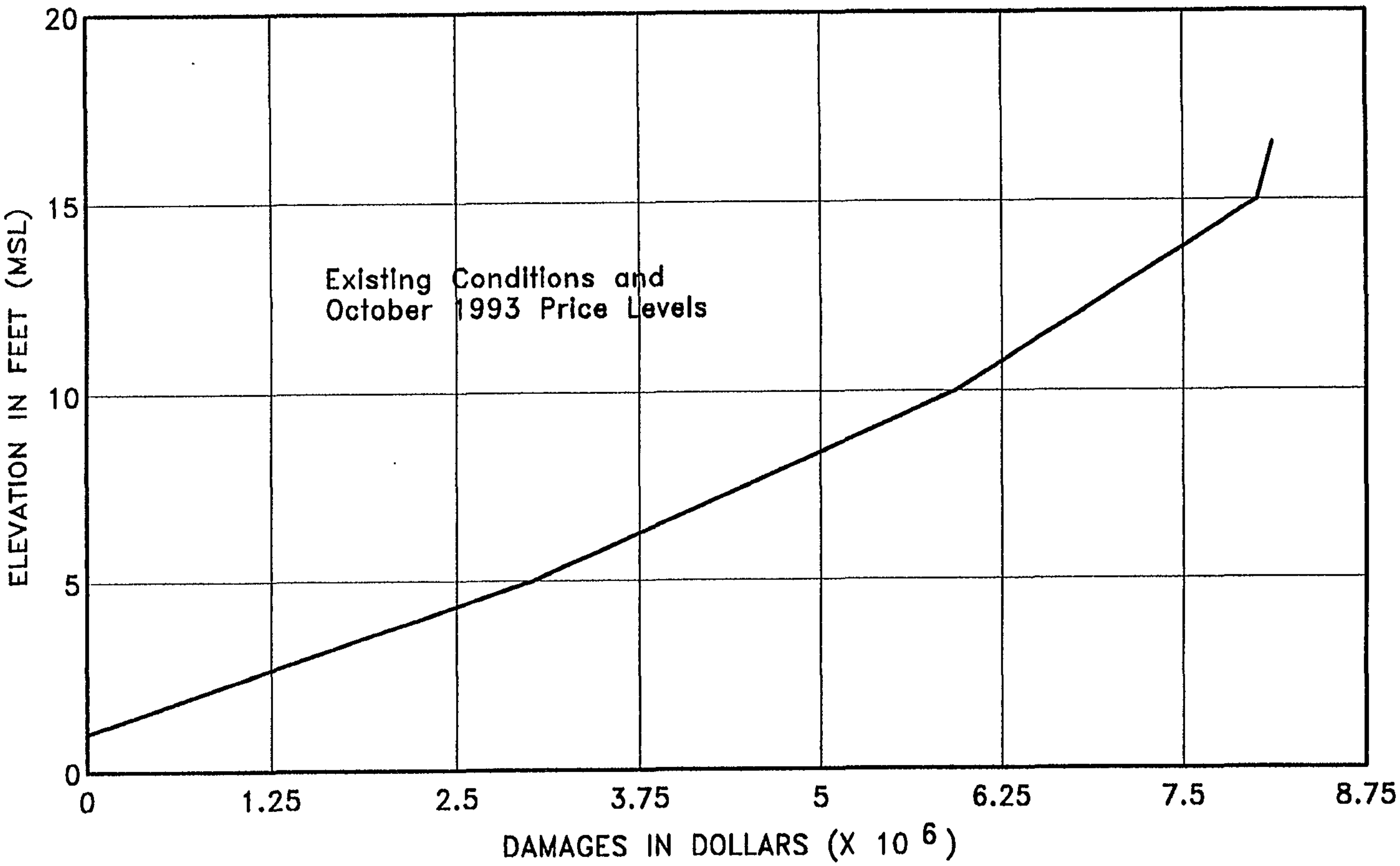
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

DAMAGES VERSUS ELEVATION
RD 2104 (PETERS POCKET)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

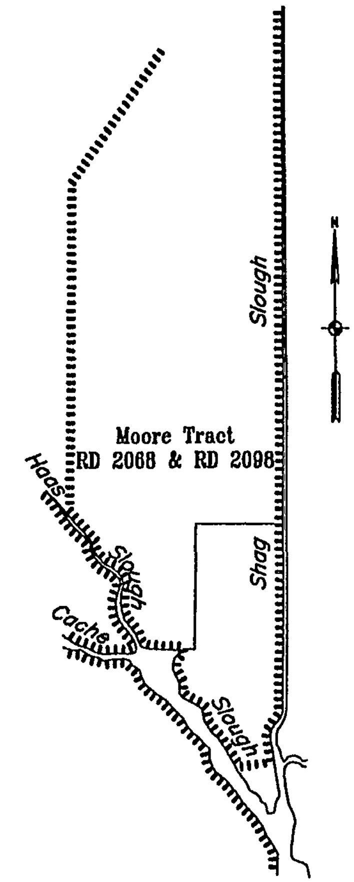
FIGURE 51

C-103447



NOTE: Damages include the cost of repairing one levee break and dewatering.

GENERAL LOCATION MAP



GENERAL LOCATION MAP

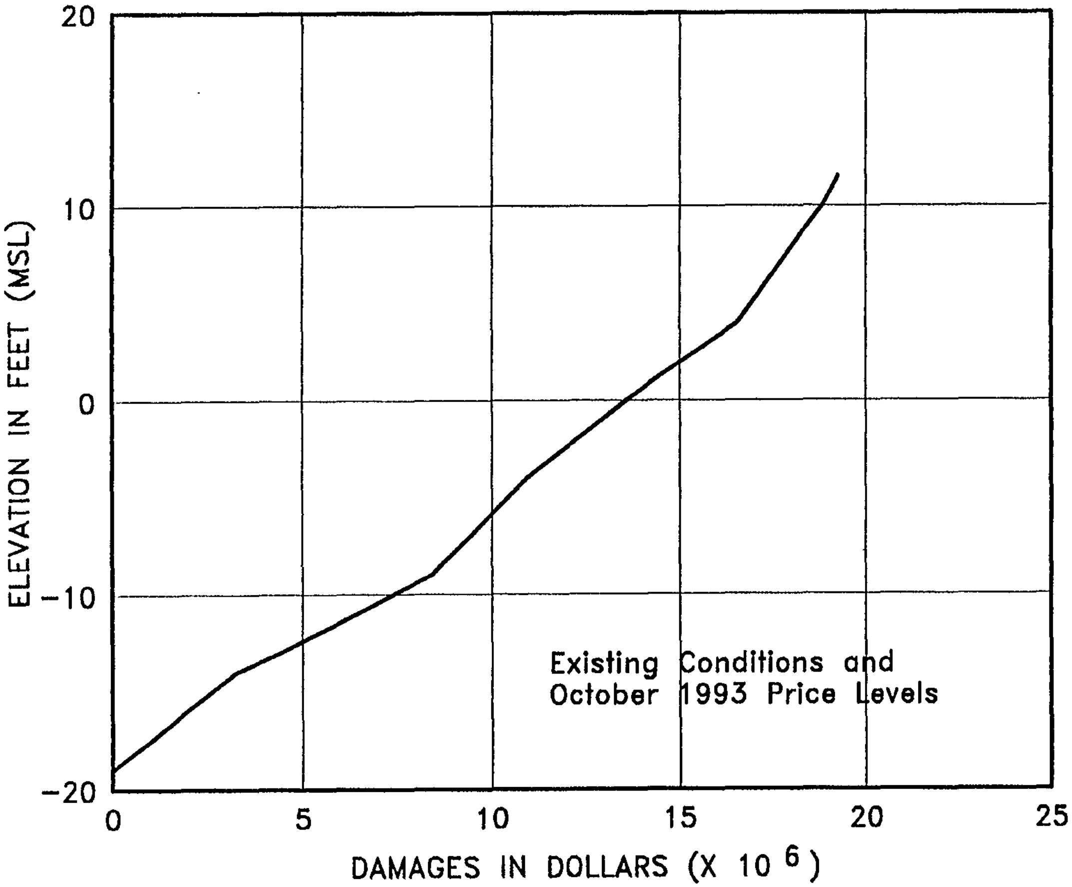
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

DAMAGES VS. ELEVATION
RD 2068 & RD 2098
(MOORE TRACT)

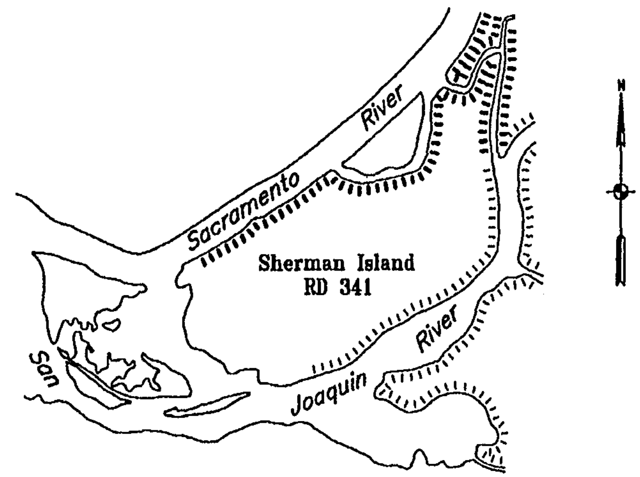
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 52

C-103448



NOTE: Damages include the cost of repairing one levee break and dewatering.



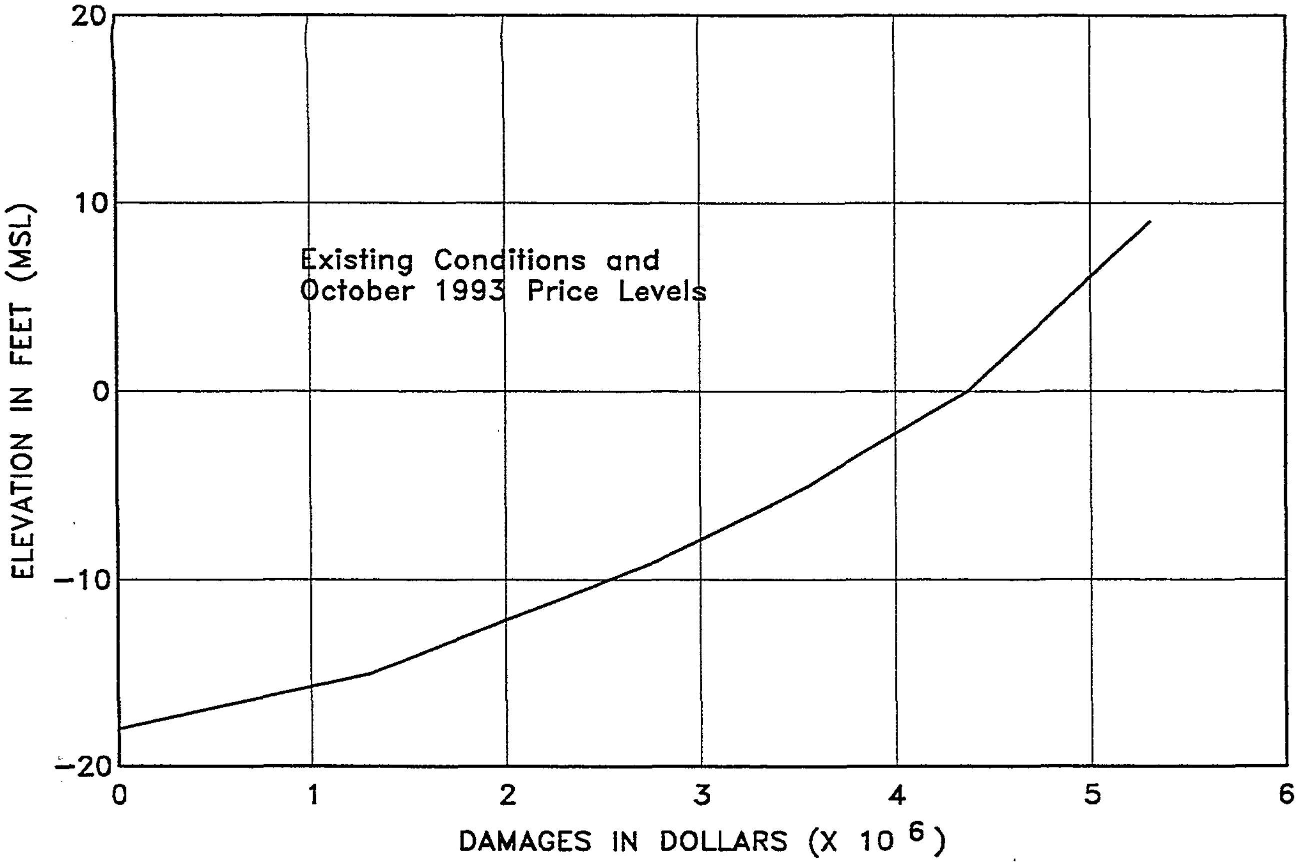
GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

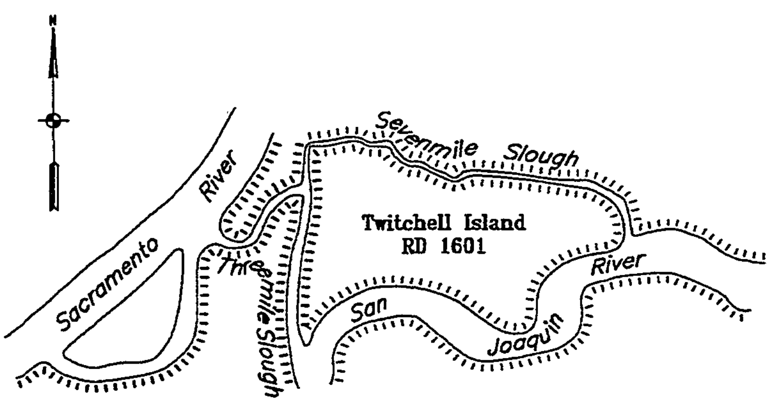
DAMAGES VERSUS ELEVATION
RD 341 (SHERMAN ISLAND)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 53



NOTE: Damages include the cost of repairing one levee break and dewatering.



GENERAL LOCATION MAP

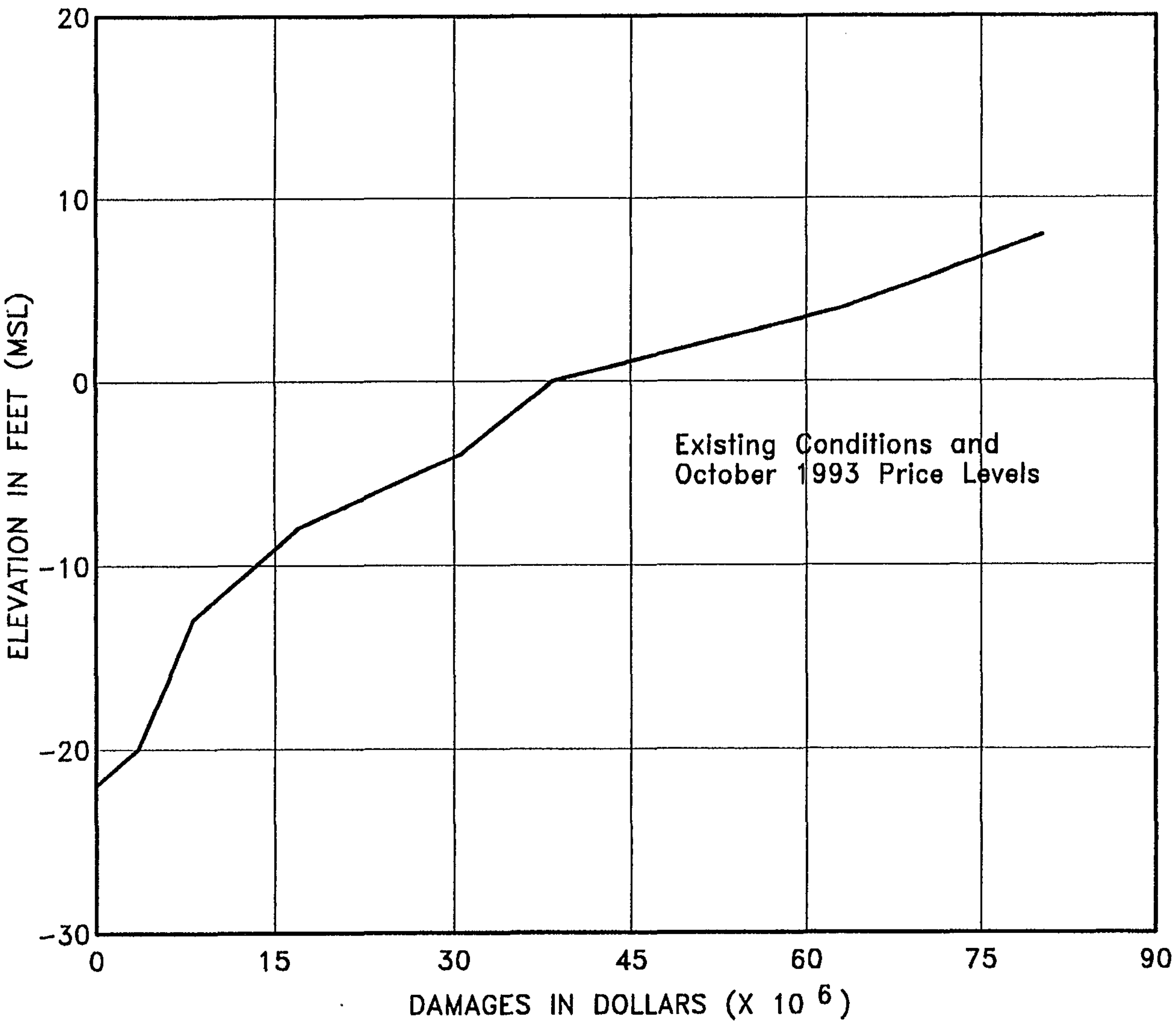
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

DAMAGES VS. ELEVATION
RD 1601 (TWITCHELL ISLAND)

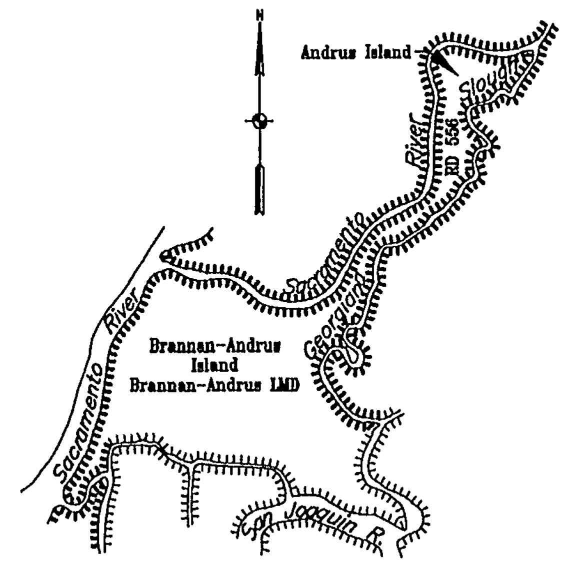
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 54

C-103450



NOTE: Damages include the cost of repairing one levee break and dewatering.



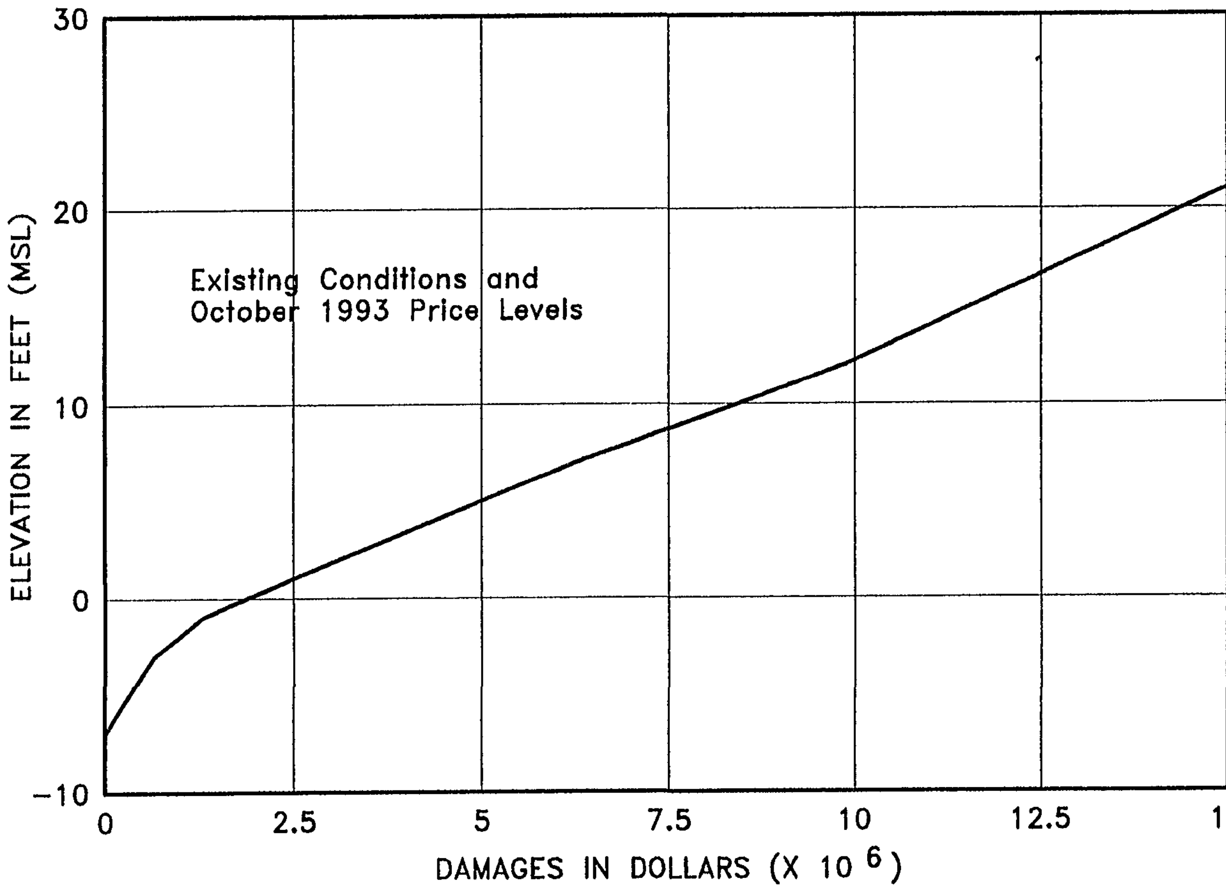
GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

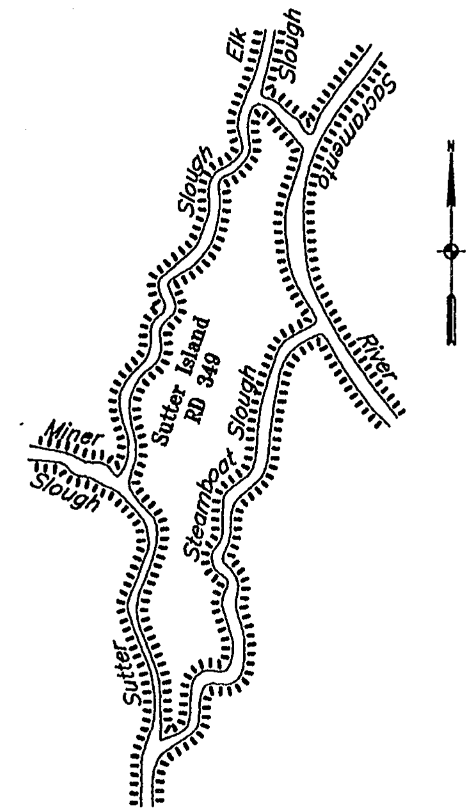
DAMAGES VS. ELEVATION
BRANNAN-ANDRUS LEVEE MAINTENANCE DIST. & RD 556
(BRANNAN-ANDRUS AND ANDRUS ISLAND)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 55



NOTE: Damages include the cost of repairing one levee break and dewatering.



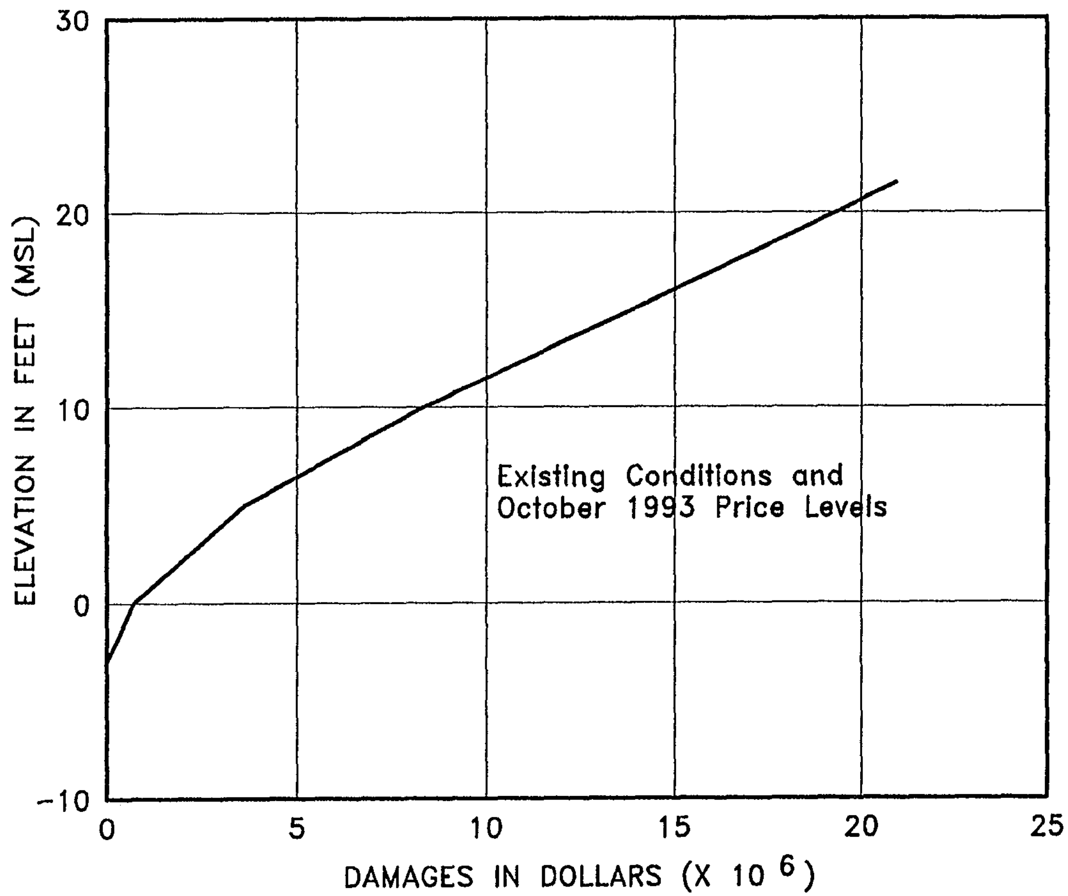
GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

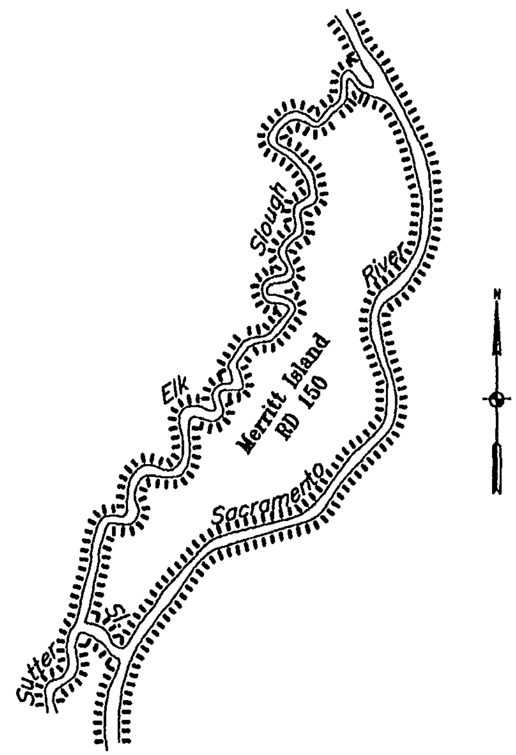
DAMAGES VS. ELEVATION
RD 349 (SUTTER ISLAND)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 56



NOTE: Damages include the cost of repairing one levee break and dewatering.



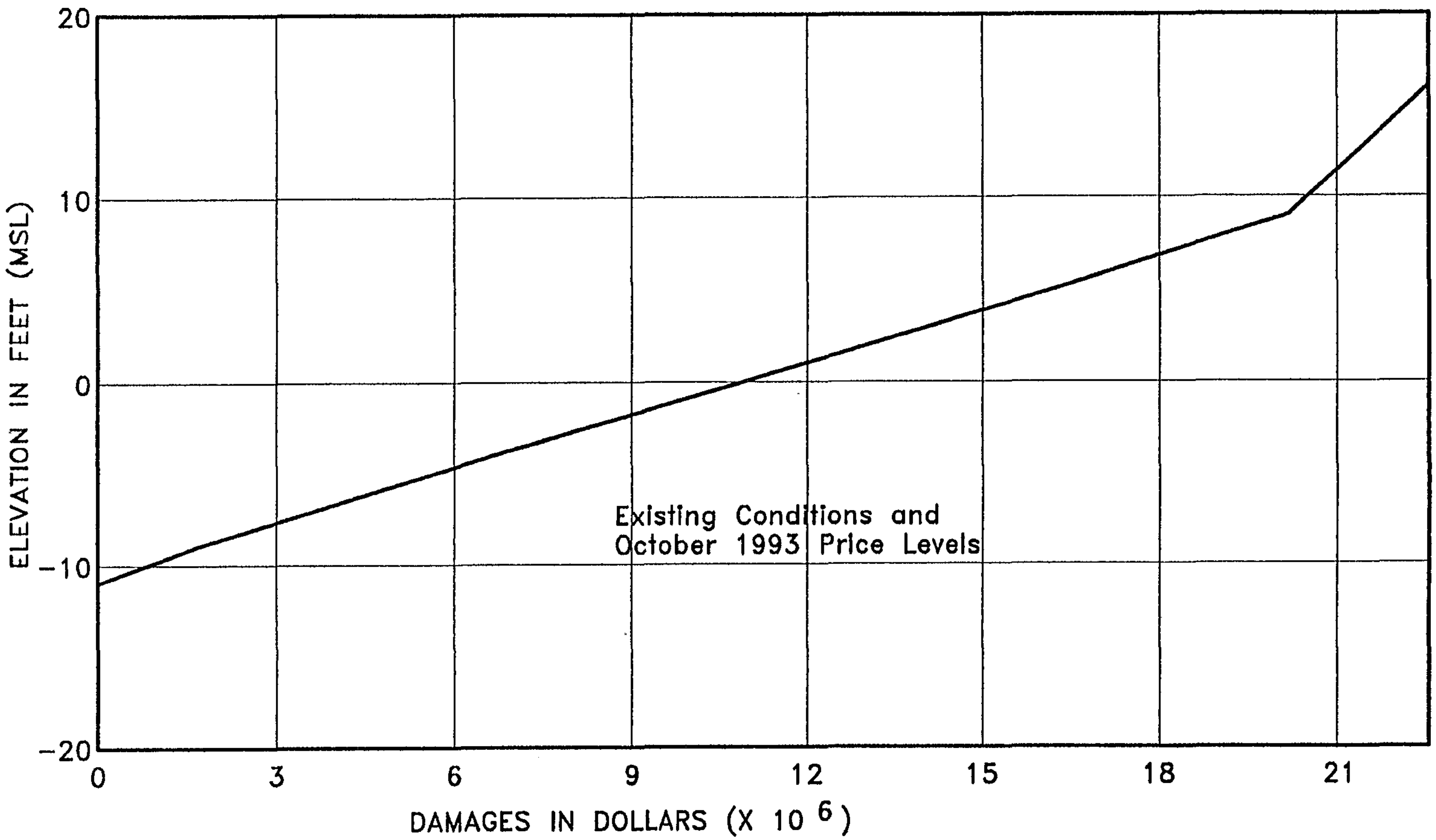
GENERAL LOCATION MAP

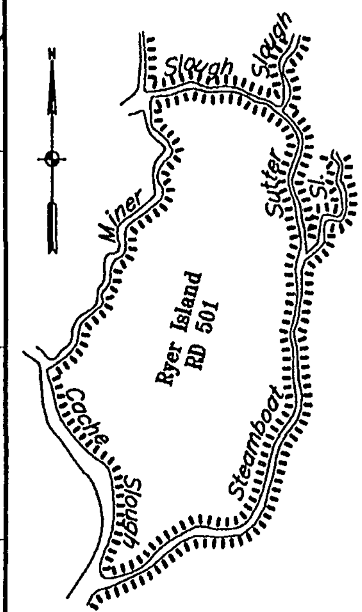
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

DAMAGES VS. ELEVATION
RD 150 (MERRITT ISLAND)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 57





GENERAL LOCATION MAP

NOTE: Damages include the cost of repairing one levee break and dewatering.

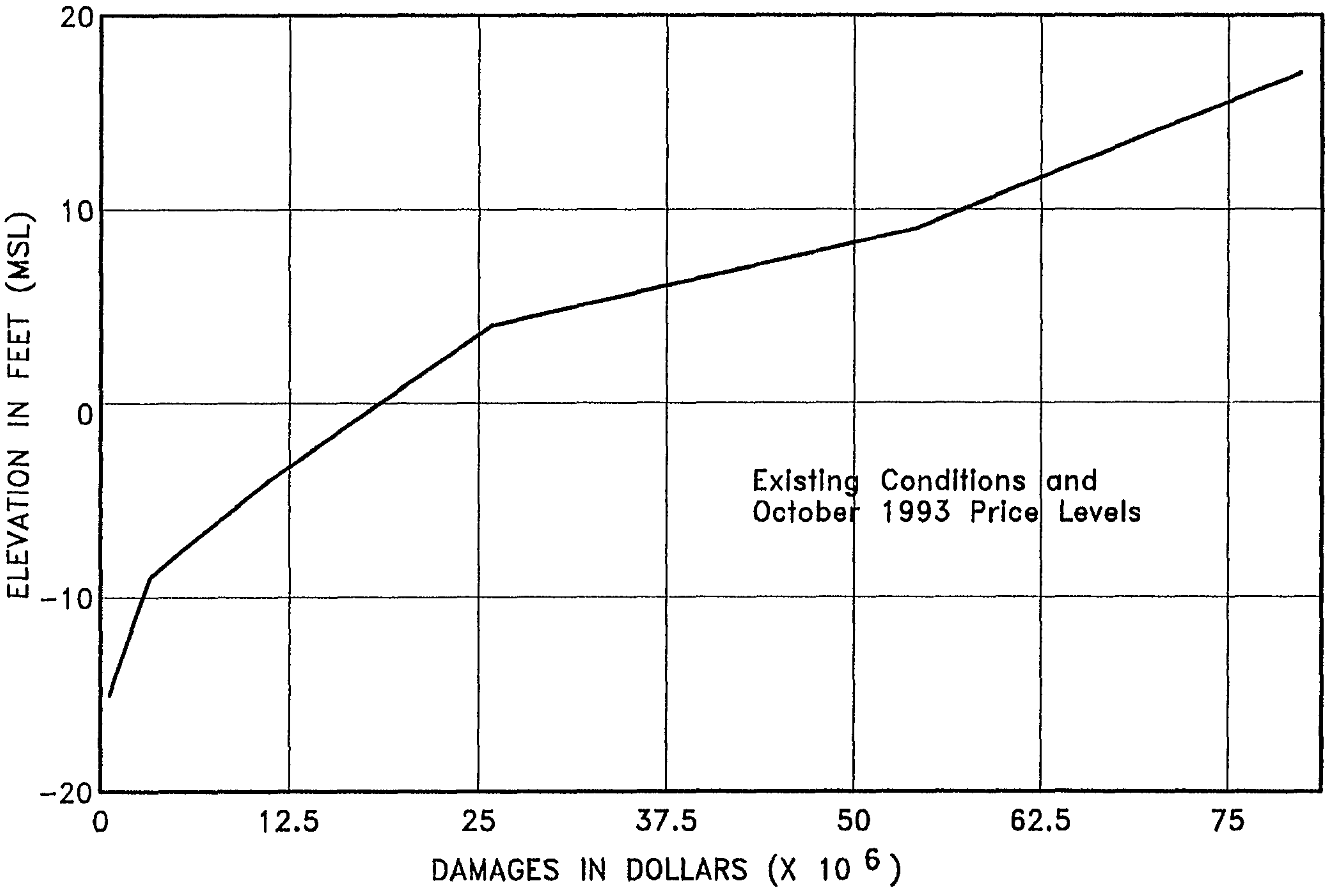
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

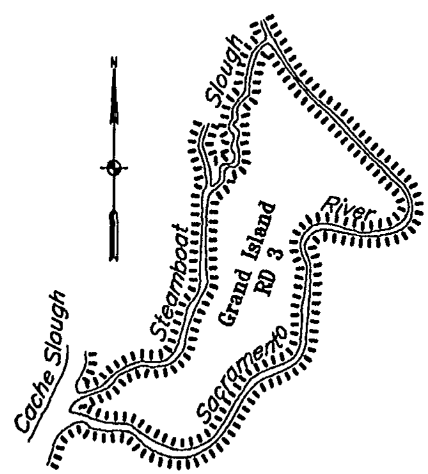
DAMAGES VS. ELEVATION
RD 501 (RYER ISLAND)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 58

C-103454





GENERAL LOCATION MAP

NOTE: Damages include the cost of repairing one levee break and dewatering.

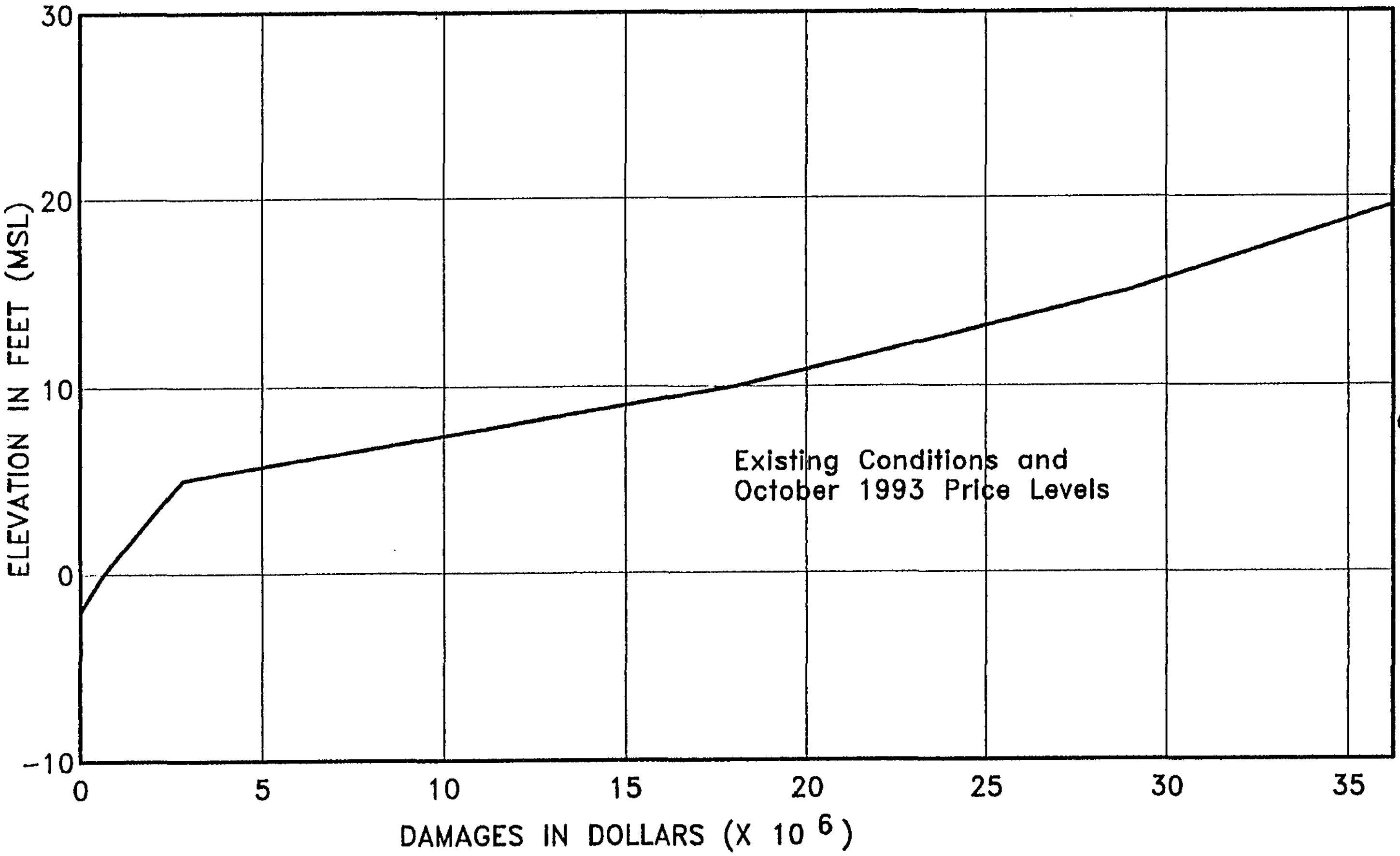
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

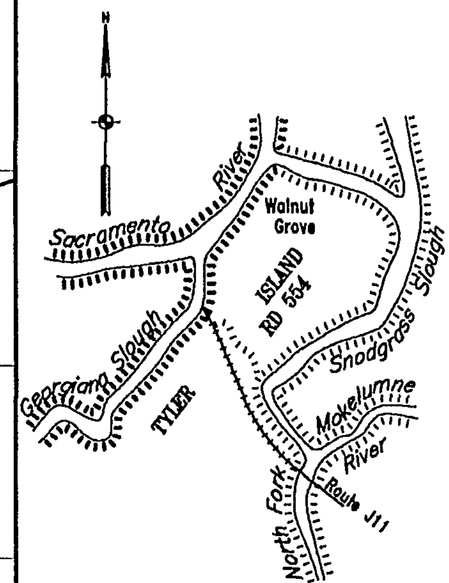
DAMAGES VS. ELEVATION
RD 3 (GRAND ISLAND)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 59

C-103455





GENERAL LOCATION MAP

NOTE: Damages include the cost of repairing one levee break and dewatering.

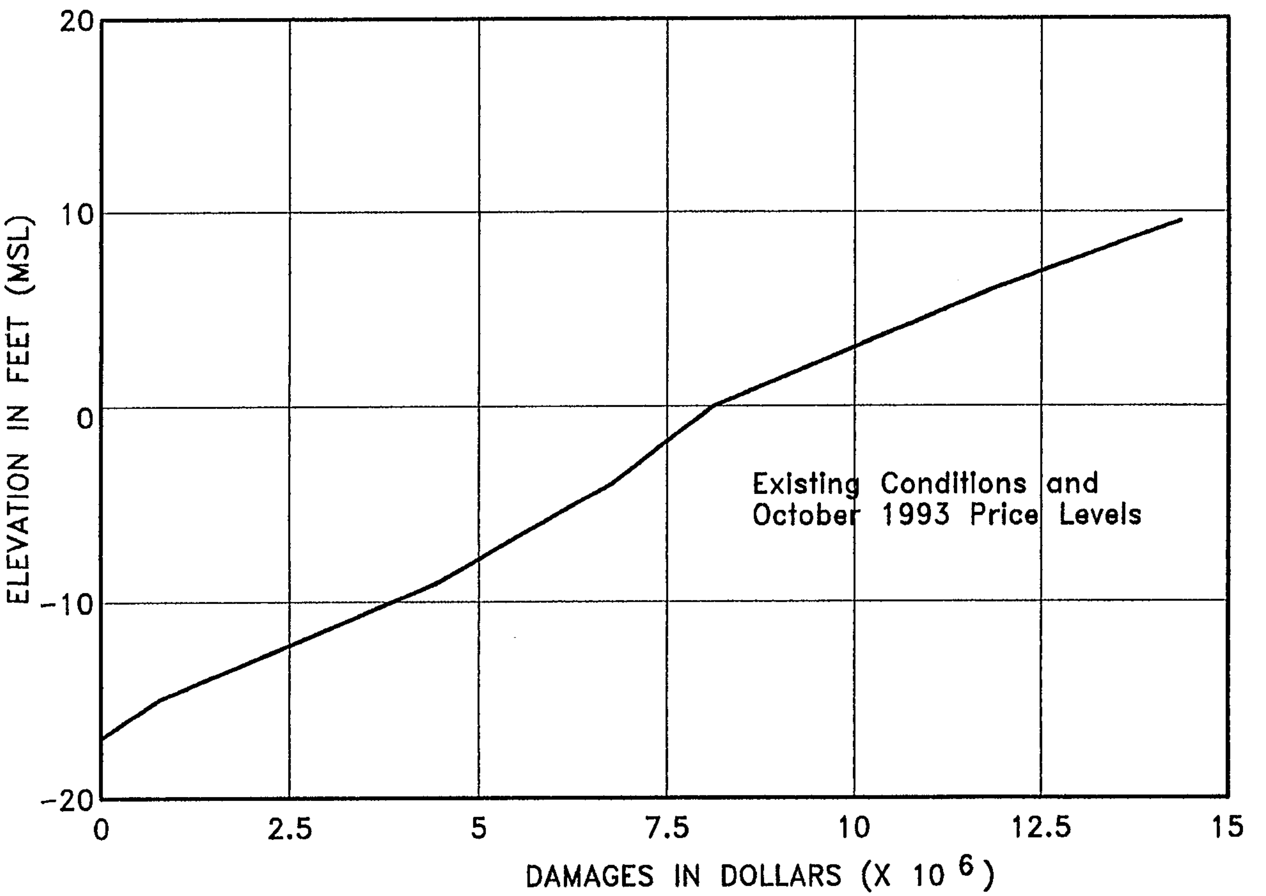
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

DAMAGES VS. ELEVATION
RD 554 (TYLER ISLAND)
NORTH OF ROUTH J11

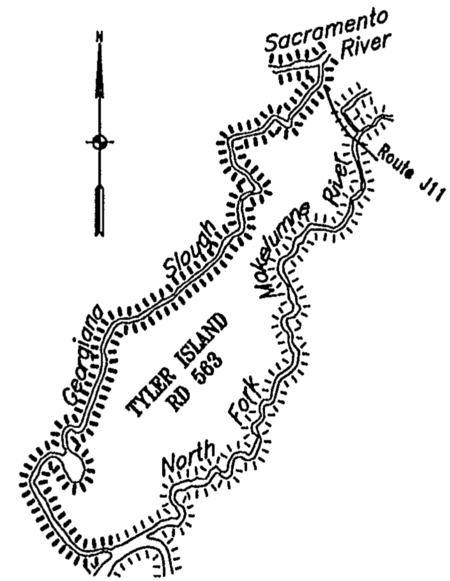
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 60

C-103456



NOTE: Damages include the cost of repairing one levee break and dewatering.



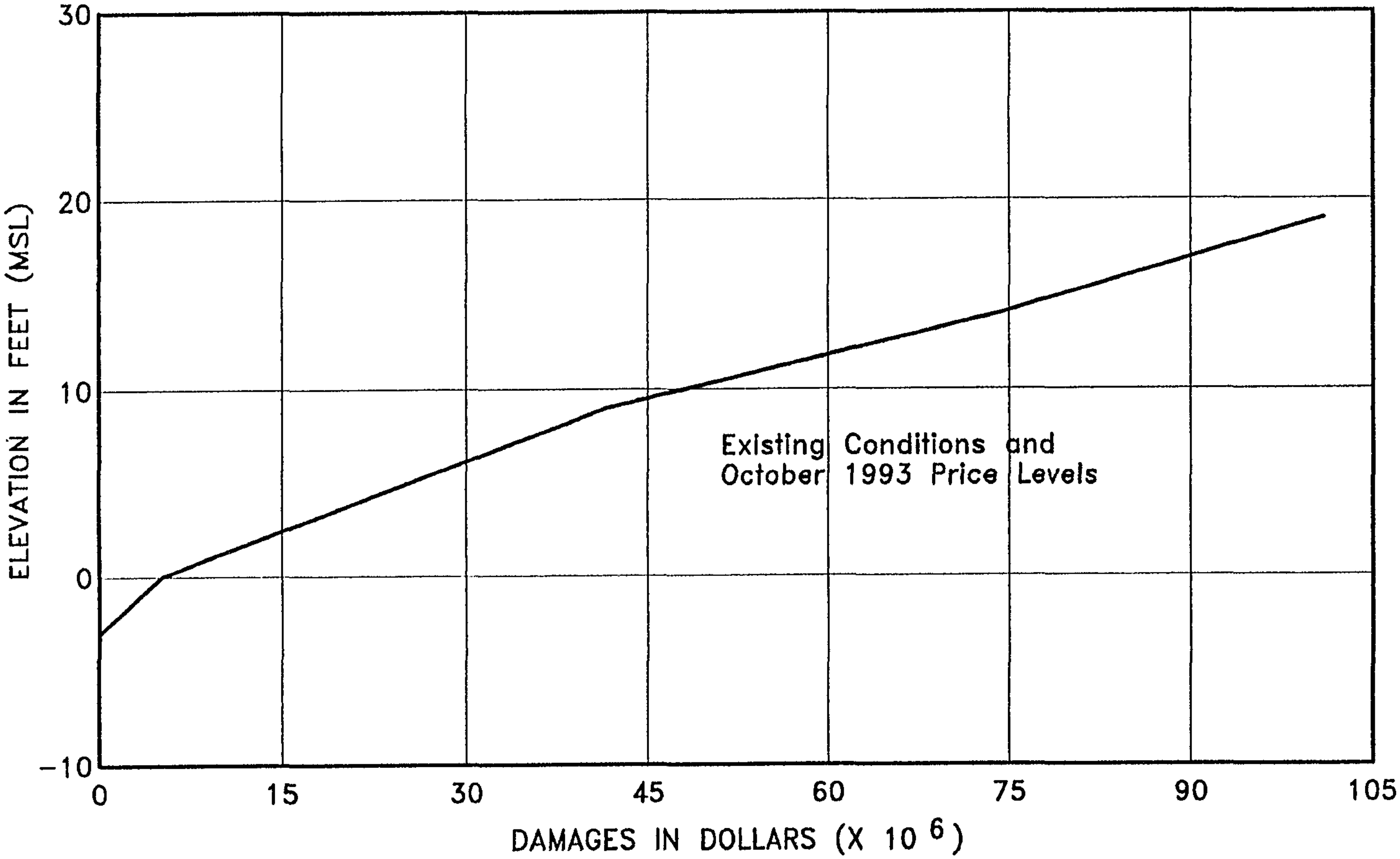
GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

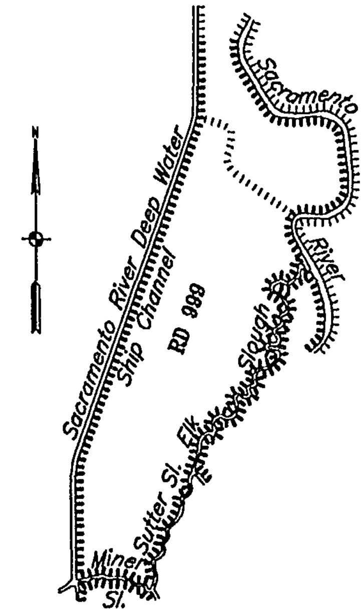
DAMAGES VS. ELEVATION
RD 563 (TYLER ISLAND)
SOUTH OF ROUTE J11

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 61



NOTE: Damages include the cost of repairing one levee break and dewatering.



GENERAL LOCATION MAP

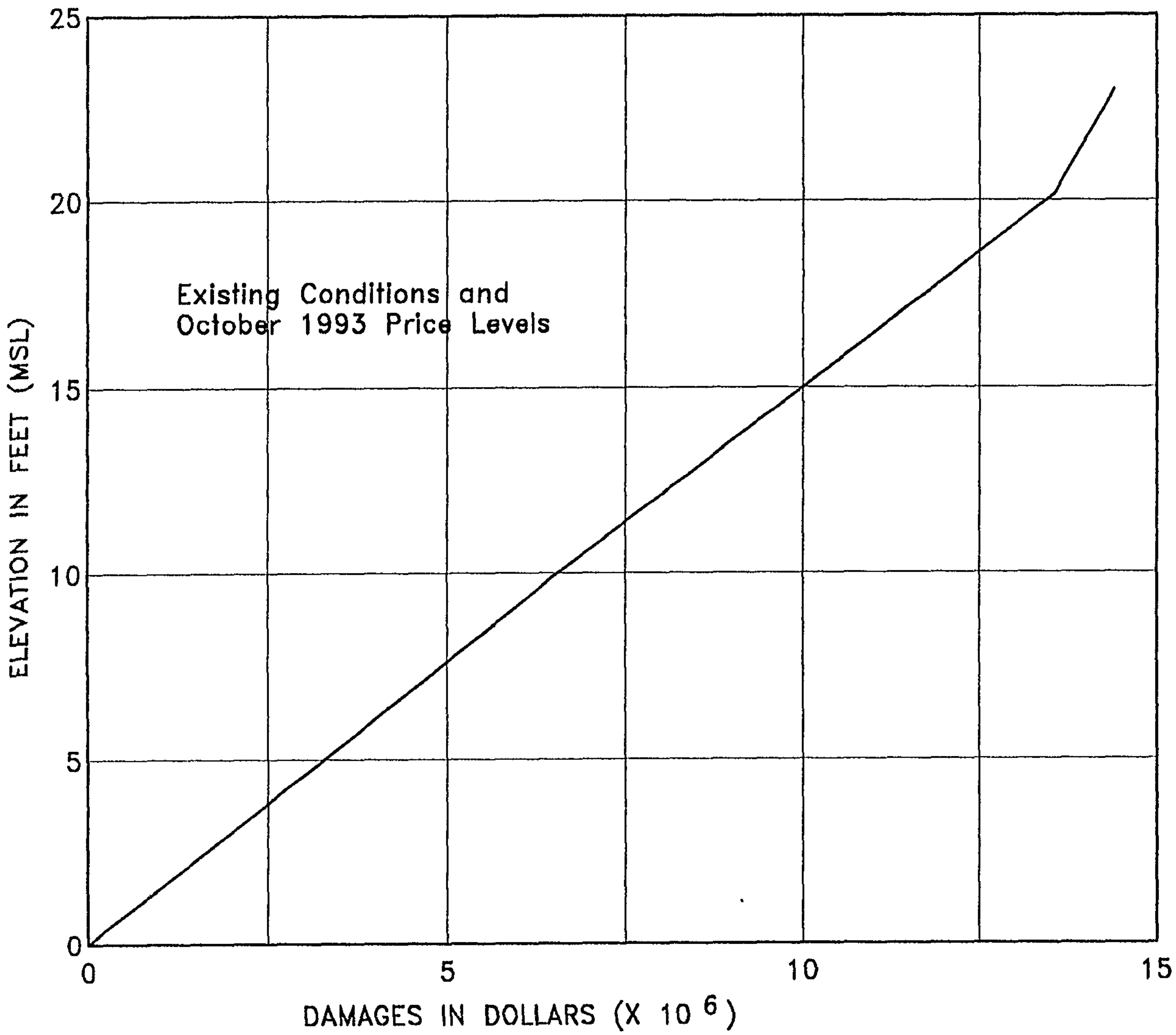
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

DAMAGES VS. ELEVATION
RD 999

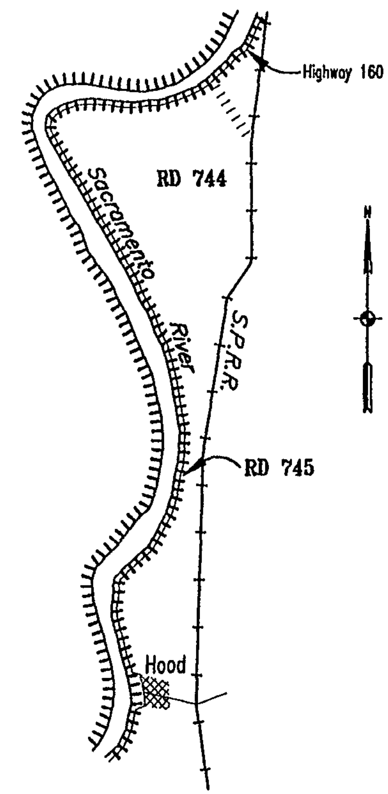
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 62

C-103458



NOTE: Damages include the cost of repairing one levee break and dewatering.



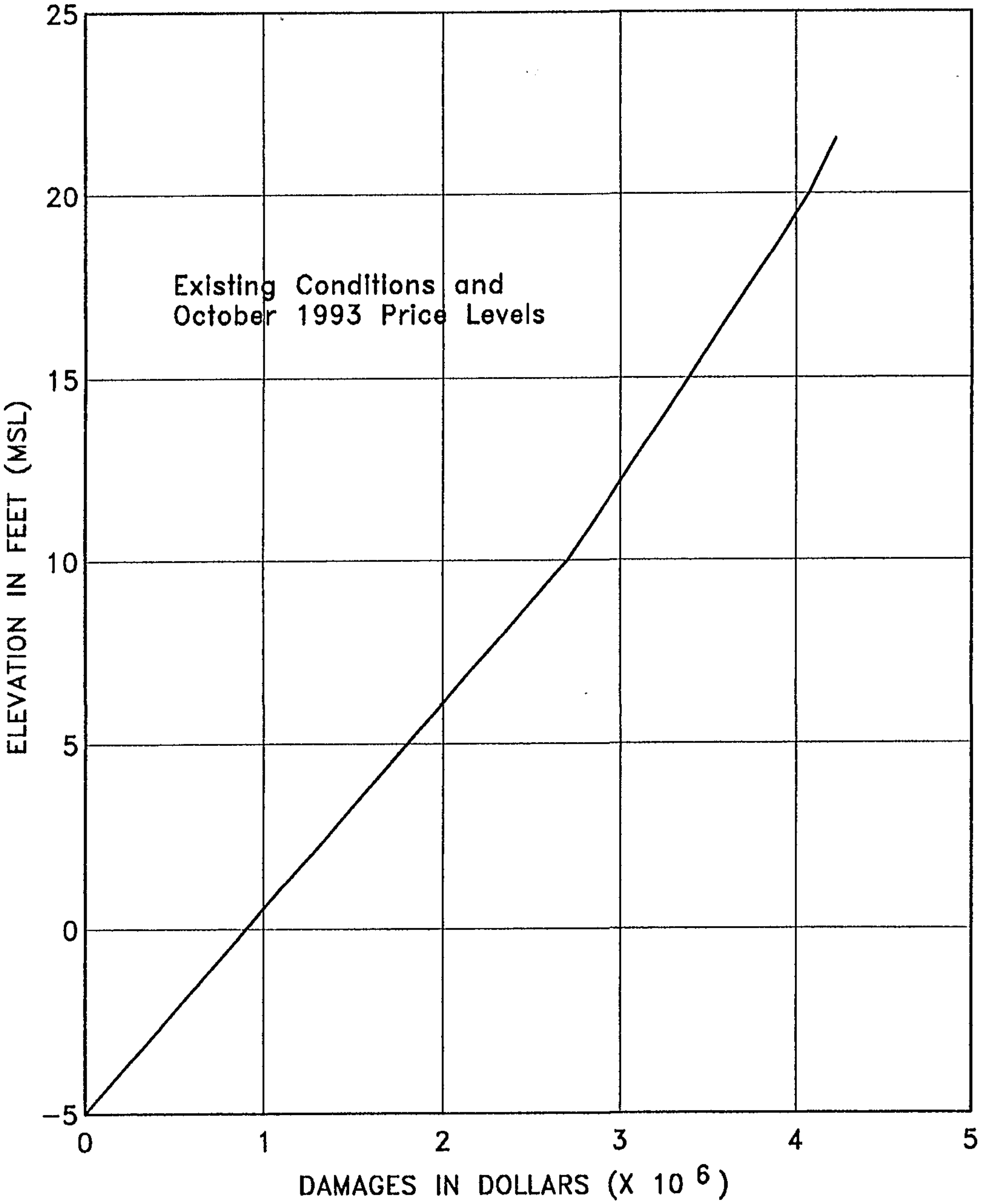
GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

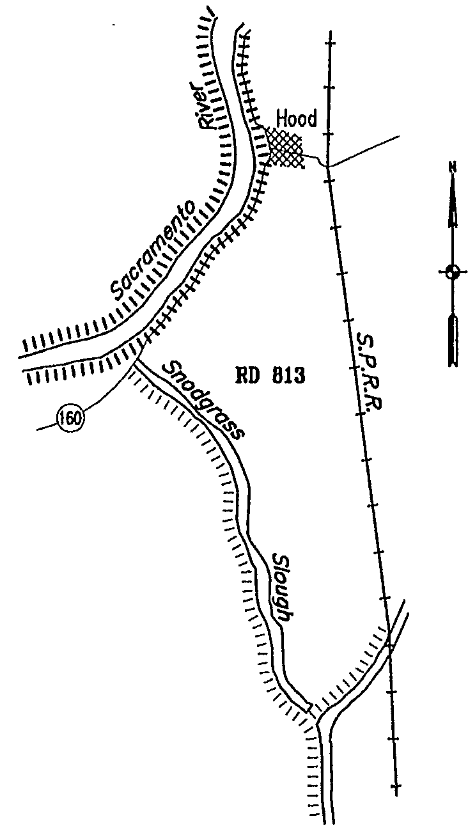
DAMAGES VS. ELEVATION
MA 9 (HOOD AREA)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 63



NOTE: Damages include the cost of repairing one levee break and dewatering.



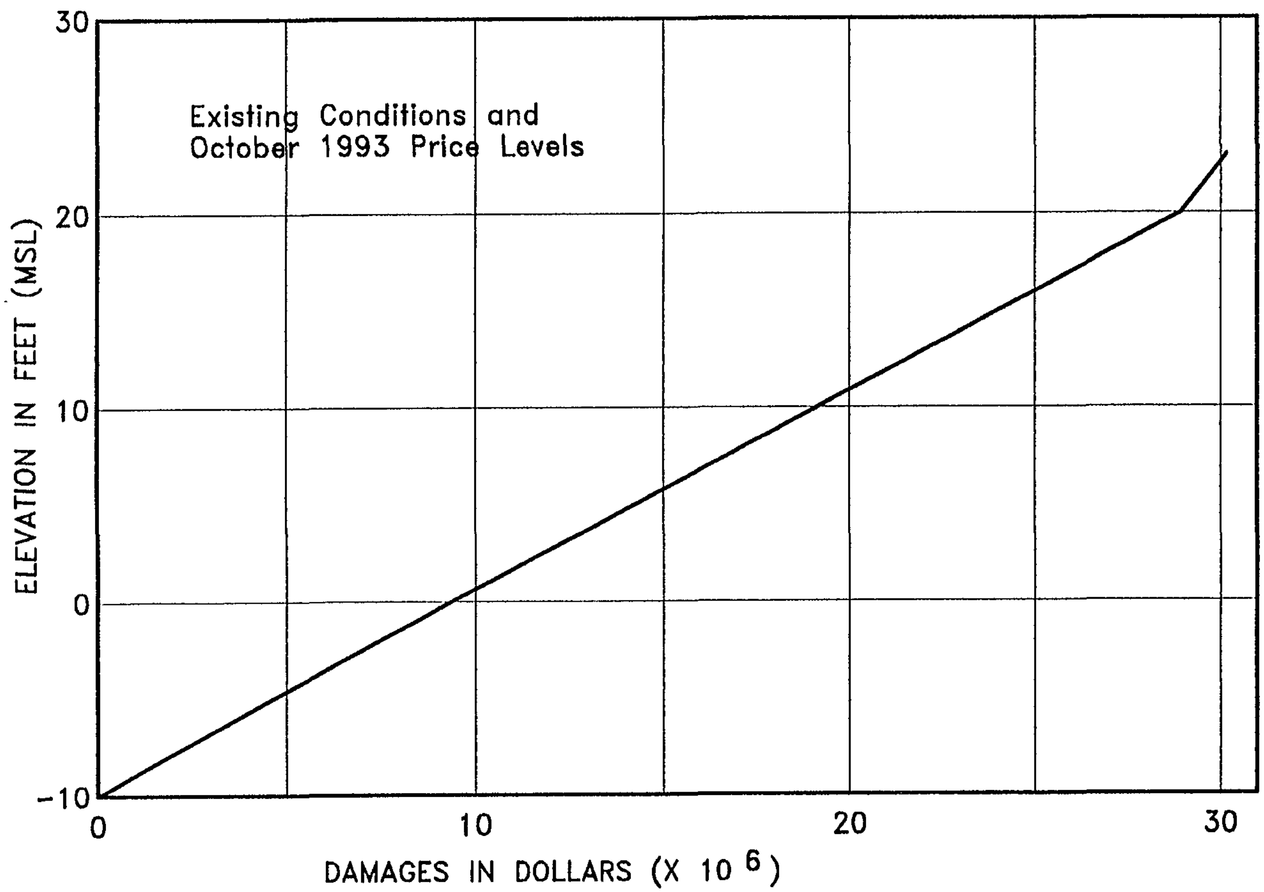
GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

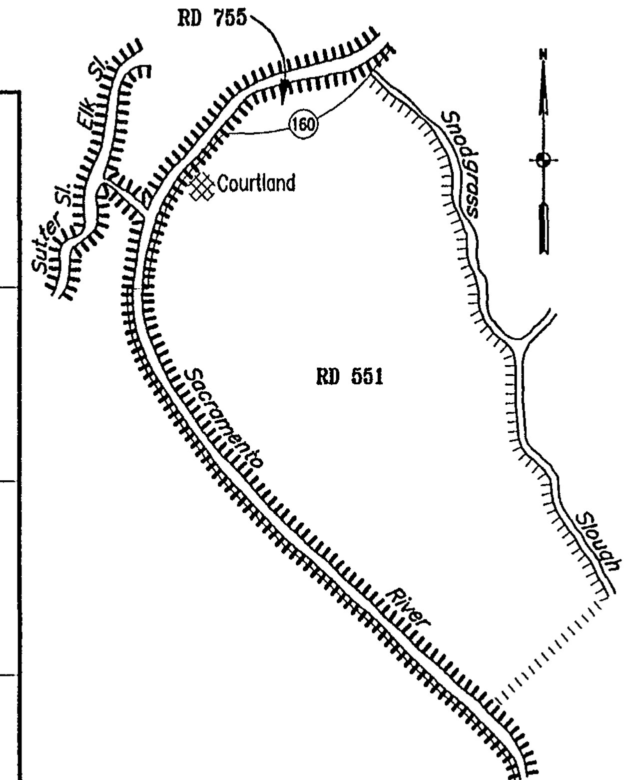
DAMAGES VS. ELEVATION
MA 9
(HOOD TO SNODGRASS SLOUGH)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 64



NOTE: Damages include the cost of repairing one levee break and dewatering.



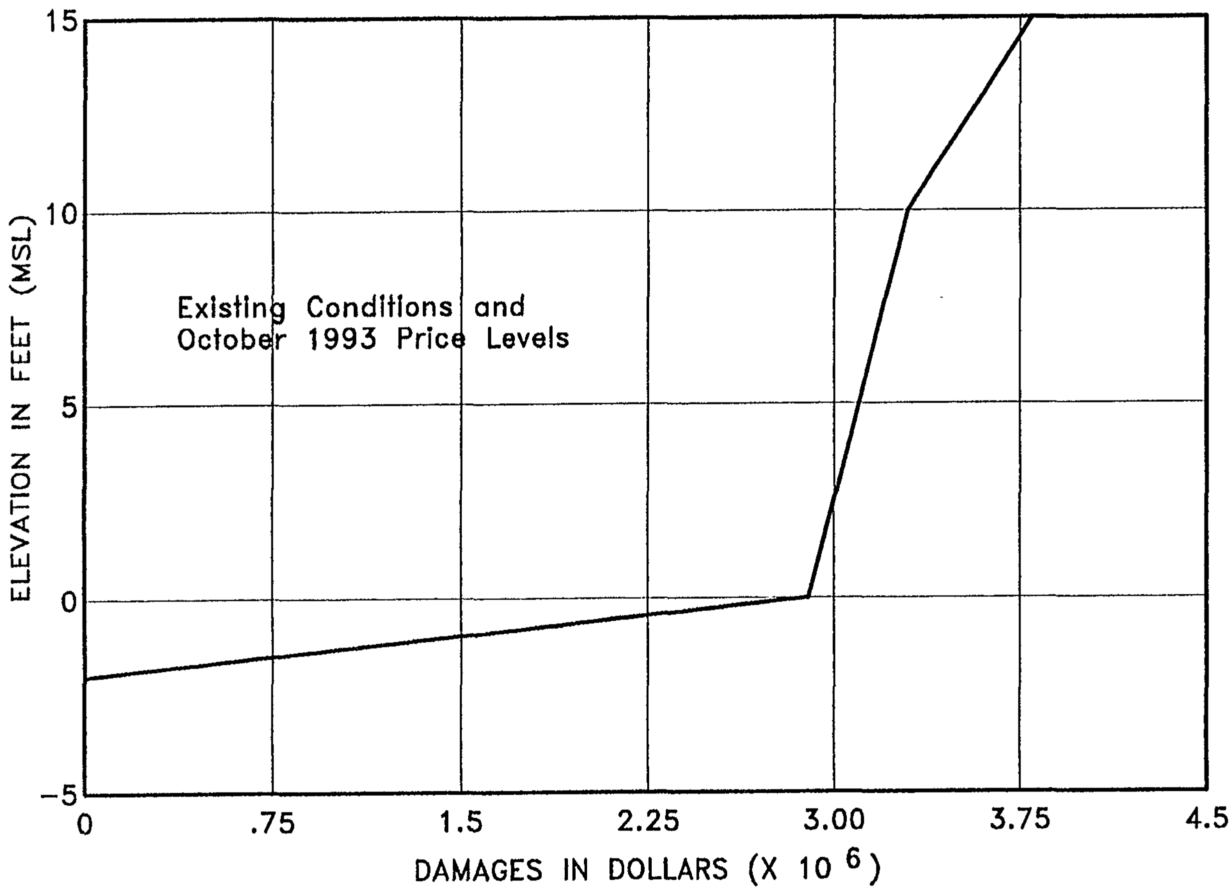
GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

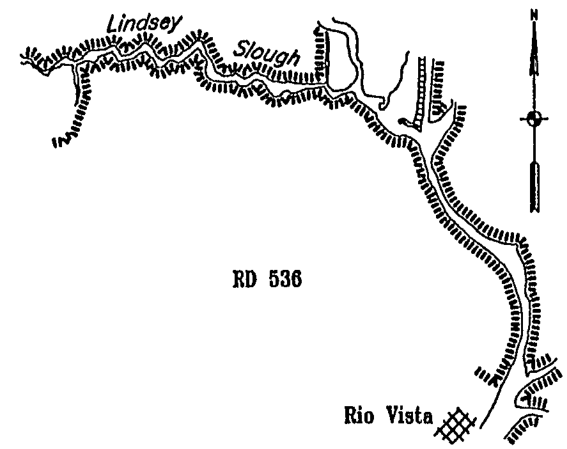
DAMAGES VS. ELEVATION
RD 551 (COURTLAND AREA)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 65



NOTE: Damages include the cost of repairing one levee break and dewatering.



GENERAL LOCATION MAP

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

DAMAGES VS. ELEVATION
RD 536 (S. LINDSEY SLOUGH)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 66

C—103462

TABLE 8

AREA, MAXIMUM DAMAGES, ELEVATION OF MAXIMUM DAMAGES, AND RECONSTRUCTION COSTS

Area	Area (tract)	Acres	Total Damages ($millions) (Oct 1993)	MSL Depth of Maximum Damages	Reconstruction Costs ($ millions) (Oct 93)
1	RD 2060 (Hastings A)	4,350	6.3	16.0	2.1
2*	RD 2060 (Hastings B)	668	1.5	18.5	.-
3*	RD 2060 (Hastings C)	1,440	1.7	17.5	.-
4	RD 2104 (Peters Pocket)	1,390	2.1	16.5	8.3
5	RD 2098 and 2068 (Moore Tract)	11,050	8.2	16.5	10.8
6	RD 341 (Sherman Island)	10,100	19.2	11.5	0.9
7	RD 1601 (Twitchell Island)	3,539	5.3	9.0	7.9
8	Brannan-Andrus Levee Maintenance District (RDs 317, 407, and 2067) and RD 556 (Brannan-Andrus and Andrus Islands)	14,957	80.4	8.0	22.5
9	RD 349 (Sutter Island)	2,515	15.0	21.0	0.3
10	RD 150 (Merritt Island)	4,720	21.0	21.5	0.2
11	RD 501 (Ryer Island)	11,750	22.6	16.0	1.6
12	RD 3 (Grand Island)	16,520	79.5	17.0	1.7
13*	RD 554 (N. Tyler Island)	469	36.5	19.5	.-
14	RD 563 (S. Tyler Island)	8,750	14.4	9.5	6.7
15	RD 999 (The Big Area)	32,907	101.5	19.0	0.2
16	Maintenance Area 9 (Hood Area)	3,249	14.4	23.0	6.4
17*	Maintenance Area 9 (Hood to Snodgrass Slough)	2,366	4.2	23.0	.-
18*	RD 551 (Courtland Area)	9,209	30.3	23.0	.-
19	RD 536 (S. Lindsey Slough)	7,436	3.8	15.0	0.8
	Total	147,385	466.1		70.4

NOTE: * denotes area with no proposed reconstruction.

sensitivity analysis was performed by Economics staff from the Corps of Engineers (Sacramento District) to determine the potential costs of levee reconstruction which might be economically justified on an incremental basis.

Five of the areas with deficiencies also have non-Federal levees which protect the area from flooding from other tributaries and rivers. The areas protected by both non-Federal levees and Federal levees include RD 341 (Sherman Island); RD 1601 (Twitchell Island); Brannan-Andrus Levee Maintenance District (which includes RD 317, RD 407, and RD 2067) and RD 556 (Brannan-Andrus and Andrus Island); RD 563 (Tyler Island South); Maintenance Area 9 (Hood area); and Maintenance Area 9 (Hood to Snodgrass Slough). The non-Federal levees are on the San Joaquin River, North Mokelumne River, and Snodgrass Slough. It is probable that repairs on the Federal levees will not increase the level of flood protection because the non-Federal levees are likely to fail at much lower levels.

Problems have been documented on the non-Federal levees on Sherman, Twitchell, Brannan-Andrus, and Tyler Islands. During the February 1986 flood, two portions of the non-Federal levee on Tyler Island on the North Mokelumne River failed and flooded most of Tyler Island. Only emergency work (a temporary levee) prevented the city of Walnut Grove from flooding. A non-Federal levee failed on Sherman Island in 1969 and another failed on Andrus Island in 1972, as previously discussed in the Historic Flooding section of this report.

Since reconstructing the Federal levees on these islands would not increase the current level of flood protection, there is no incremental justification (benefit-cost ratio is less than 1.0) for RD 341 (Sherman Island), RD 1601 (Twitchell Island), Brannan-Andrus Levee Maintenance District and RD 556 (Andrus Island), and RD 563 (Tyler Island).

Comparisons of maximum potential flood damages versus reconstruction costs shown on Table 8 show RD 2104 (Peters Pocket) $2.1 million maximum damages versus $8.3 million reconstruction cost, RDs 2098 and 2068 (Moore Tract) $8.2 million maximum damages versus $10.8 million reconstruction cost, and RD 1601 (Twitchell Island) $5.3 million maximum damages versus $7.9 million reconstruction cost are incrementally infeasible.

The objective of the above sensitivity analysis for the 13 flood hazard areas of Figure 44 was to determine if the proposed levee reconstruction could be incrementally justified based on flood damage assessments under existing conditions. In addition, information has been provided that would indicate possible maximum flood damages that could be expected during large flood events and the number and type of structures that could be affected. This information should indicate that economic justification based on an incremental analysis is not likely for some of the areas under consideration.

As in the case of the Initial Appraisal Report for the Marysville/Yuba City Area and Mid-Valley Area, a system approach is also deemed appropriate for the economic analysis. Based on directions contained in a January 6, 1986, letter (4th Endorsement) from the Director of Civil Works (Major General H. J. Hatch), Federal responsibility should be determined by evaluating the net benefits of rehabilitating the project (the Sacramento River Flood Control Project) to ensure the design level of flood protection. In addition, the Congressionally authorized Sacramento River Flood Control Project was economically justified based on a comparison of total system costs and benefits.

A Limited Reevaluation Report (LRR) has been prepared for the Sacramento River Flood Control Project in response to instructions in the Fiscal Year 1993 Congressional Work Allowance. The LRR evaluates, based on available information, the economic feasibility of repairing the Sacramento River Flood Control Project levee system to its original design on a systemwide basis. If the design flows could be conveyed in upstream reaches, then these design flows would reach other downstream portions of the Sacramento River Flood Control Project levees. Since reconstruction of the levees would ensure that the design flows reached downstream locations, it appears appropriate that the downstream levees should also be able to accommodate the Congressionally authorized design flows. In addition, upstream flood control storage facilities were economically justified and are currently operated by various Federal, State, and local agencies under the assumption that the project levees can and have always been able to safely convey the design flow at the design water surface. Because of the interrelationship of different parts of the flood control projects to each other, a systems approach has been taken in the LRR based on approved or best available information.

CHAPTER V - LEVEE EMBANKMENT RECONSTRUCTION

The process of developing and evaluating levee embankment reconstruction plans in the study area is discussed in this chapter. The process includes defining objectives, identifying reconstruction plans, developing and evaluating plans, and identifying plans in which there is a Federal interest.

OBJECTIVES

As discussed in previous sections, this study was conducted to evaluate the integrity of and level of flood protection provided by the existing Sacramento River Flood Control Project levees; to determine whether the levees function as designed; and, if reconstruction is needed, to determine the Federal interest in proceeding with construction. The existing levee embankments of the Sacramento River Flood Control Project were constructed based on (1) a design discharge, (2) a design water surface, and (3) a minimum freeboard requirement above the design water surface. In general, the study objective was to develop reconstruction plans such that the project levees could safely pass the design flow (according to existing Corps criteria and guidance) at the design water surface.

RECONSTRUCTION PLANS

Based on the objectives described, several types of problems were identified in the previous sections and include the following:

Geotechnical

The primary problems related to levee embankment integrity in the study area is the susceptibility of the embankment and foundation soils to seepage and piping. Historic levee problem areas of this and other types are shown on Plate 3 and discussed in Attachment B, "Basis of Design, Geotechnical Evaluation of Levees for Sacramento River Flood Control System Evaluation, Lower Sacramento River Area, Phase IV," February 1993.

Design Freeboard

Various reaches of levee embankment have deficient design freeboard. These levees do not have the minimum freeboard between the design water surface and top of levee (levee crown) specified for the Sacramento River Flood Control Project levees. In addition, several railroad and road crossings create localized depressed areas of the levee embankment crown that encroach into the design freeboard.

Additional studies will be done during preparation of the Design Memorandum to determine how much, if any, additional freeboard may be necessary due to future subsidence. Levees on many portions of the Lower Sacramento Area can be expected to subside due to poor foundation conditions caused by peat deposits. The amount of subsidence will be dependent on peat depths and thicknesses and can be very localized. Freeboard may need to be increased and/or operation and maintenance efforts increased from what has historically been done to achieve a 50-year design life.

Design Flow

Localized areas of the flood control project cannot convey the design flow within the design water surface. Locations of design flow deficiencies are indicated on Figure 47. In general, the local sponsor, The Reclamation Board (State of California), is responsible, under the existing project operation and maintenance agreement, for ensuring that the design flow can be conveyed at or within the design water surface.

The following paragraphs discuss levee reconstruction plans that can be used to correct the problems cited above. The plans considered are the most likely types of reconstruction and corrective measures based on the information available to date and are used as a basis for developing costs and benefits.

Various alternative plans were considered by the Corps of Engineers geotechnical staff to correct for levee height deficiencies and stability and seepage problems within the levee embankment and foundation soils. (The plans, which included levee raising, slurry cutoff walls, landside seepage berms with toe drains, landside stability berms, relocation of existing toe drainage ditches, and drainage collector systems, would add levee height and/or provide the necessary stability and seepage control.) Based on geotechnical engineering, environmental, and cost considerations, about 34 miles of levee raising, 0.2 mile of landside berm with cutoff wall, 8.8 miles of landside seepage berm with toe drains, 3.2 miles of levee raising and landside berm with toe drain, and 0.3 mile of drainage collector system are recommended at the locations shown in Plate 4.

An alternative to construct a landside stability berm with slurry cutoff wall near the toe of the levee was the environmentally preferred alternative near a wetlands site on Georgiana Slough. The landside stability berm would stabilize the levee embankment and foundation while avoiding habitat impacts. The construction of the landside slurry cutoff wall near the levee toe reduces the impacts to the wetlands by clearing a portion of the wetlands for construction of a wide berm.

Cost estimates have been developed for the corrective measures (as shown in Figures 67 through 73) and for mitigation. Basis for costs is discussed in Chapter V, Design and Construction Costs.

About 17.8 miles of levees on Cache Creek, Willow Slough Bypass, and Putah Creek have deficient design freeboard. Maintenance records and field observations do not indicate significant levee embankment problem areas along Cache Creek, Willow Slough Bypass, and Putah Creek which would suggest why so many miles of these levees have deficient design freeboard. Recent studies of subsidence in the Sacramento Valley by the U.S. Geological Survey and other agencies indicate ground-water pumping has an impact on many ground elevations west of Yolo Bypass. Areas where deficiencies are caused by manmade impacts (such as ground-water pumping) have no Federal interest and must be addressed by the local sponsor.

Generally, in the locations where reconstruction is proposed, the Sacramento River Flood Control Project levee design is for a 20-foot crown width, a 3:1 waterside slope, and a 2:1 landside slope. The project design standards were used for the reconstruction plans, except where minor transitions were required between the proposed and existing levee embankments. In levee reaches where both levee raising and toe berms with drains are proposed (see Figure 69), the toe berm is incorporated within the plan for levee raising (the toe berm would be constructed at the landside toe of the existing levee embankment).

For the reconstruction plans proposed above, temporary construction easements (for a period of 3 years) are required for working areas, staging areas, access, and borrow and disposal sites. The majority of the temporary easements involve a 20-foot strip adjacent to the permanent easement boundary. A permanent easement up to a maximum of 40 feet may be required at some landside berm and levee raising sites.

In conjunction with railroad and road crossings that encroach into the design freeboard and/or design water surface (crossings that create localized depressed areas in the levee crown as shown on Plates 5 through 19), those crossings, in general, were incorporated or approved as part of the Sacramento River Flood Control Project. Flood gates and sandbags (or different methods) can and have been used to provide a temporary barrier against floodwater that could flow over the levee embankment at these locations.

To ensure that the design flow can be conveyed safely within the project levees at the design water surface, all railroad crossings, road crossings, and localized depressed areas of the levee crown that encroach into the design freeboard should have

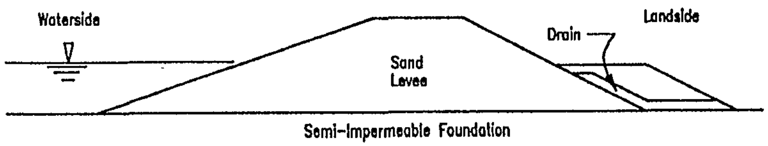


FIGURE 67 – TYPICAL CROSS SECTION
LANDSIDE BERM WITH SLOPING DRAIN

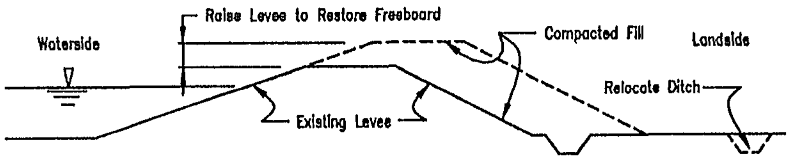


FIGURE 68 – TYPICAL CROSS SECTION
LEVEE RAISING AND DITCH RELOCATION

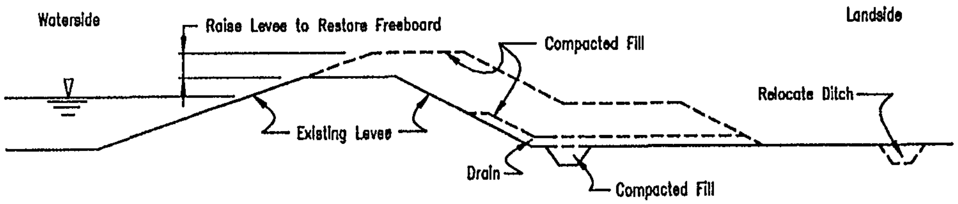


FIGURE 69 – TYPICAL CROSS SECTION
LEVEE RAISING, LANDSIDE BERM, SLOPING DRAIN, & DITCH RELOCATION

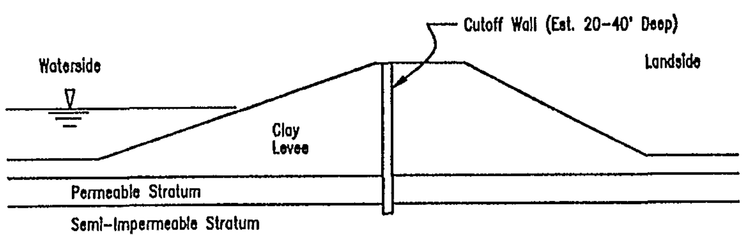


FIGURE 70 – TYPICAL CROSS SECTION
CUTOFF WALL CONSTRUCTION

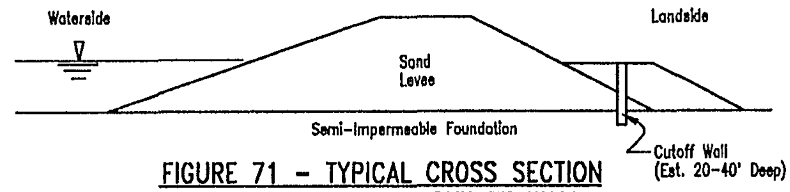


FIGURE 71 – TYPICAL CROSS SECTION
LANDSIDE BERM WITH CUTOFF WALL

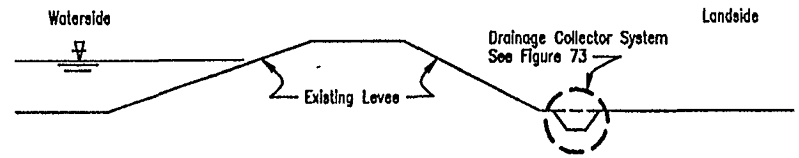


FIGURE 72 – TYPICAL CROSS SECTION
DRAINAGE COLLECTOR SYSTEM

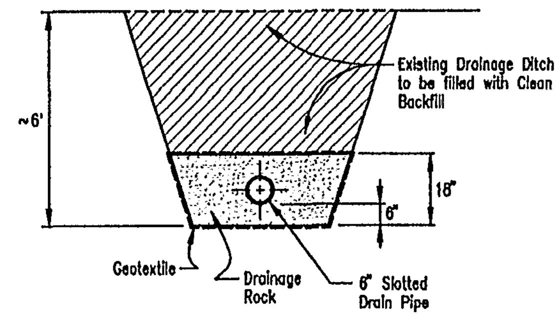


FIGURE 73 – DETAIL
DRAINAGE COLLECTOR SYSTEM

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE EMBANKMENT RECONSTRUCTION ALTERNATIVES

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURES 67–73

an operation schedule specified for installing flood barriers. As part of the proposed reconstruction work recommended in this study, the Corps, in coordination with The Reclamation Board, would define an operation for installing flood barriers at each crossing with deficient design freeboard. At the time levee modifications are constructed, the operations developed would be included as an addendum or modification to the Corps current Operation and Maintenance Manual for project levees. Flood barriers would provide the necessary design freeboard (see Table 2) above the design water surface. Installation of a flood barrier would be based on actual and projected flood stages at the crossing location and would be the responsibility of The Reclamation Board.

Since the railroad crossings were initially adopted as part of the Sacramento River Flood Control Project, sandbagging would have been required during extreme flood stages as part of the operation of the project. Instead of relying on the installation of a flood barrier, the maintaining agencies should fill in depressed areas.

The design flow <u>could not</u> be conveyed within the design water surface in the Willow Slough Bypass and in the Yolo Bypass south of Interstate 80 based on information available from the February 1986 flood and information developed for this investigation and the Mid-Valley Initial Appraisal Report as well as the American River Watershed Investigation and Sacramento Metropolitan Area Investigations. After the February 1986 flood, significant physical changes have occurred (see section on Design Flow) that may reduce the extent of levee reaches with potential design flow deficiencies. This study was authorized as part of a comprehensive analysis of the long-term integrity of the Sacramento River Flood Control System. Although design flow deficiencies are noted, an evaluation of corrective measures is beyond the scope of the Corps study authority unless the deficiency is a design defect.

Since The Reclamation Board is the local entity responsible for the maintenance and operation of the existing Sacramento River Flood Control Project, it is the State's obligation to ensure that the design flow can be conveyed within the design water surface (assuming that the levee embankments can convey the design flow without levee failure). Independent of the reconstruction work recommended in this study, the Board will be required to evaluate in detail each of the levee reaches cited above to determine potential causes of any design flow deficiencies and to develop measures for eliminating those deficiencies. To ensure that the design flow can be conveyed safely within the project levees at the design water surface, The Reclamation Board would be required to implement corrective measures (such as dredging, clearing, levee modifications, etc.)

at its expense under the existing Sacramento River Flood Control Project operation and maintenance requirements.

ENVIRONMENTAL EFFECTS

An environmental evaluation (EE) is included as Attachment C to this report and provides baseline information on fish and wildlife resources in the study area. The EE also provides a general assessment of potential impacts of project alternatives and associated mitigation costs. Included in this evaluation is a description of the environmental setting for the study area, fisheries, wildlife, and threatened or endangered species. A U.S. Fish and Wildlife Service Planning Aid Letter (PAL) is an appendix to the EE. The PAL provides detailed, site-specific recommendations for mitigating impacts to fish and wildlife due to proposed reconstruction identified in this IAR.

A programmatic environmental impact statement (EIS) and environmental impact report (EIR) has been prepared for Phases II through V of the Sacramento River Flood Control System Evaluation to comply with the requirements of the National Environmental Policy Act and the California Environmental Quality Act. During the engineering and design (E&D) when site-specific information is available, a supplemental environmental document will be prepared for each of the above phases. The programmatic EIS/EIR was filed with the Environmental Protection Agency (EPA) in June 1992 and a Record of Decision (ROD) was filed in November 1992.

Potential Environmental Impacts

The primary (direct) environmental impact associated with the proposed reconstruction work is the removal of vegetation, which in turn adversely affects wildlife species dependent on vegetative cover. Estimates of this impact were based on 1992 and 1993 aerial photographs of the study area and field reconnaissance. About 237 acres of wildlife habitat would be affected, including 157 acres of grassland, 49 acres of wetlands, 8 acres of shrub/scrub, 3 acres of agricultural, and 20 acres of wetland/shrub/scrub complex. No significant impacts to fisheries, water quality, and aquatic resources would result. A 404(b) (1) Water Quality Evaluation will be prepared in future design phases of this study for relocation of ditches, ponds, and for potential waterside levee work. Short-term construction-related increases in noise levels, traffic, and dust are expected but considered insignificant.

Cultural Resources

A cultural resources overview of the project area was prepared for the Corps in July 1993 ("Cultural Resources Survey, Sacramento River System Evaluation, Phase IV," Dames & Moore). No sites are listed in the National Register of Historic Places. Prefield research consisted of a review of ethnographic and historic literature and maps, archeological base maps and site records, survey reports, and atlases of historic places on file at the North Central Information Center at California State University, Sacramento and the Northwest Information Center at Sonoma State University. No previously recorded sites were located within the project area. Five sites were located in the general vicinity of the project levees.

Following the prefield research, a pedestrian survey for areas of potential effects identified and recorded one historic site consisting of two railroad berms separated by Georgiana Slough. Because it is believed the site will not be disturbed, the Corps did not evaluate the site for the National Register of Historic Places.

Mitigation Measures and Costs

Mitigation measures include reseeding all disturbed areas and newly constructed berms and acquiring a parcel of agricultural land that could be revegetated with the appropriate types of wildlife habitat. About 200 acres of agricultural land (depending on final designs) would be required to mitigate adverse environmental impacts if all the reconstruction work identified on Plate 4 were completed. The mitigation requirements would be refined by conducting a habitat evaluation procedure (HEP) analysis at the affected sites during future engineering and design phases of this investigation.

Possible mitigation areas include a 120-acre block of agricultural land on Twitchell Island (owned by the State of California), a 65-acre block of land near the Cache Slough mitigation site, and a 20-acre block of land near the disposal site on Grand Island (owned by the Corps of Engineers). The cost of acquiring about 205 acres of mitigation land would range from $250,000 to $750,000, depending on the number of parcels involved and location and type of land. In addition, the cost to convert the land to wildlife habitat ranges from about $10,000 to $35,000 per acre, based on similar efforts by the Corps in the past. This cost per acre includes the establishment and maintenance of the habitat for 3 years.

Active Swainson's hawk nests close to reconstruction sites could be adversely affected by construction activities. If any active nests are affected by construction activities, schedules, work areas, and types of work efforts would be modified to avoid disturbing the nests. This practice was successfully implemented in the Sacramento Urban Area levee reconstruction project. Prior to construction activities, Swainson's hawk surveys would be done to avoid impacts to this species.

The environmental mitigation costs are about $12 million (including lands) at the maximum and are included within the total reconstruction cost presented in this report.

HTRW Sites

All borrow, borrow sites, and project lands will need to be free of HTRW before the lands can be used for project reconstruction. It is the responsibility of the State of California to ensure that all project lands are free of HTRW before levee reconstruction begins. Some of the potential borrow sites have already been certified as being free of HTRW. The Corps field investigation of the reconstruction sites in the Lower Sacramento Area provided no evidence of HTRW existence.

HTRW is most likely to be discovered near old storage tanks and drums deposited or stockpiled near levees. There are agricultural sheds located near the levee toe along the Yolo Bypass in RD 2098, but there were no obvious HTRW problems.

DESIGN, REAL ESTATE, AND CONSTRUCTION COSTS

As previously indicated in the section on Reconstruction Plans, cost estimates have been developed for 34 miles of levee raising, 0.2 mile of landside berm with cutoff wall, 8.8 miles of landside seepage berm with toe drain, 3.2 miles of levee raising and landside berm with toe drain, and 0.3 mile of drainage collector system. Plate 4 shows the general location of reconstruction work and the types of reconstruction recommended. The potential alternatives recommended at each site, shown in Figures 67 through 73, were developed based on engineering, economic, and environmental considerations. Future engineering and design efforts, including additional geotechnical explorations, cultural subsurface testing, and environmental coordination, could modify the designs, but changes in cost and potential cost-sharing amounts are not expected to be significant.

Permanent and temporary land easements required for construction at each site are predominantly agricultural, both row and orchard crops. A warehouse on top of the levee and one house close to the landside levee toe at Hood and several power poles and standpipes at various Delta sloughs and the Yolo Bypass are located within the easement areas. Three borrow areas are required to provide the necessary volume of embankment material for levee raising and landside toe berms (a total of about 1.5 million cubic yards of material is needed). A disposal site (or sites) is required to dispose of excess slurry material used in the construction of the cutoff wall. The nearest landfill is currently being considered for disposal, and the costs associated with this are included as part of the construction costs. Relocations include 35,700 linear feet of powerlines, 44 pipes, 15 gates, and 4 drainage ditches (based on field inspections and a review of State levee encroachment permits in the affected areas). Additional relocations could be required if subsurface testing, future explorations, and modifications in design indicate other facilities in the construction areas.

A summary of the total cost estimate for the reconstruction plan is presented in Table 9. Real Estate information and costs are summarized in Attachment E. Cost estimates are based on October 1993 price levels. The local sponsor, The Reclamation Board, has indicated an intent to cost share the levee reconstruction (see Attachment A) in accordance with the provisions of Section 103(a) of the Water Resources Development Act of 1986. The Board will also be responsible for providing all lands, easements, and rights-of-way, including suitable borrow areas, and performing all related necessary relocations (LERRD), including LERRD required for fish and wildlife mitigation.

Based on the cost-sharing requirements of Section 103(a), The Reclamation Board will pay at least 25 percent of the total cost of the proposed reconstruction work. In addition, the Board will pay 5 percent of the total cost, in cash, during the construction of the project. The total non-Federal contribution shall not exceed 50 percent of the total project cost.

BENEFIT EVALUATION

Flood damage reduction benefits are based on a comparison of existing and with-project-condition (reconstruction work) levels of flood protection in the study area. Benefits were determined for the reduction in physical damages (damages to buildings and contents, roads, sewers, bridges, powerlines, etc.), for the reduction in emergency costs (for example, costs of evacuation and reoccupation, flood fighting, and increased costs of police and fire protection), and for losses associated with traffic disruption. Additional information is located in the Economic Evaluation, Attachment D. Benefits were based only on existing land use conditions within the flood hazard areas.

As indicated in Table 9, the total cost of the reconstruction work is about $70.4 million. The non-Federal contribution is about $17.5 million. Engineering and design costs include additional geotechnical explorations, levee embankment topographic information, and plans and specifications for the levee reconstruction.

Estimates of recurrence intervals at which levees could potentially fail under existing conditions are based on past levee performance and geotechnical considerations (see Table 7

TABLE 9

COST ESTIMATE
RECONSTRUCTION PLAN
($1,000)
October 1993 Price Level

	Feature	Federal	Non-Federal
01	Lands and Damages	1,100 [1]	4,709
02	Relocations		401
06	Fish and Wildlife Facilities	10,104	
11	Levee Modifications and Drainage Facilities	42,299	
18	Cultural Resources Preservation	528 [2]	
30	Planning, Engineering, and Design	6,719	
31	Construction Management	4,334	
33	HTRW	241	
	Subtotal	65,325	5,110
	Non-Federal Cash Contribution 5%	- 3,495	+ 3,495
	Adjustment for 25% Local Share	- 8,872	+ 8,872
	Total	52,958	17,477

1 Federal costs involved in the coordination, administration, and review of the State's real estate acquisition program.
2 Cultural Resource Preservation costs associated with mitigation and/or data recovery (up to 1 percent of the total Federal cost is not subject to cost sharing).

and section on Economics). With-project levels of flood protection assume the following:

(1) Construction of the proposed work at locations shown on Plate 4 and using designs in Figures 67, 68, 69, 70, 71, 72, and 73.

(2) Installation of flood barriers during major flood events by local maintaining agencies at each of the railroad and road crossings that encroach into the design freeboard.

(3) Implementation of maintenance measures by The Reclamation Board to eliminate or compensate for the local areas with design flow deficiencies (see Figure 47). Under the above assumptions and using guidance contained in ER 1105-2-100, with-project levels of flood protection were based on the ability of the project to pass floods greater than the design levels. Benefits were claimed for the area under the frequency-damage curve between the design level of flood protection and the nondamaging level of flood protection.

Because of the uncertainty of when, where, and how many levee breaks will occur within, adjacent to, and upstream of the study area (that would affect estimated levels of flood protection), a sensitivity analysis was used to determine a range of benefits that might be attributable to the proposed levee reconstruction (see Economics section). The values in the column under "Annual Benefit" represent a probable maximum limit to benefits claimed for each of the flood hazard areas shown in Figure 44.

Annual costs and benefits are based on a 50-year period of analysis, October 1993 price levels, and an interest rate of 8.25 percent.

The flood hazard area in RD 2060, Hastings Tract, southeast of the Hastings Cut, has a benefit-to-cost ratio less than 1.0, based on total damages of $6.3 million and reconstruction cost of about $2.2 million. This area is completely encircled by levee embankments and contains 4,350 acres, which is agricultural. The area includes about 63 residences and farm buildings as well as one public and one commercial structure and about 40 people. The first cost for the proposed reconstruction work in this area is about $2.1 million, or $190,000 annually.

The flood hazard area for RD 2104, Peters Pocket, has a benefit-to-cost ratio much less than 1.0, based on total damages of about $2.1 million and a reconstruction cost of about $8.4 million. The maximum flood plain acreage for this area is probably about 1,400 acres. The area is agricultural and includes about five structures, primarily residences and agricultural structures; no people are believed to reside in the potential flood plain. The first cost for the proposed reconstruction work in this area is about $8.4 million, or about $760,000 annually.

The flood hazard area which includes RDs 2098 and 2068, Moore Tract, has a computed benefit-to-cost ratio significantly less than 1.0, based on total damageable property of about $2.2 million and a reconstruction cost of about $10.8 million. This area, which has levee embankments on three sides, contains about 11,000 acres, predominantly agricultural. The area includes about 30 residences and farm structures and about 40 people. The total damages for Moore Tract are about $8,164,000. The first cost for the proposed reconstruction work in this area is about $10.8 million, or about $980,000 annually.

The flood hazard area for RD 341, Sherman Island, has a benefit-to-cost ratio less than 1.0, based on non-Federal levees which are likely to fail at much lower flood events than the Federal levees. Repairing of the Federal levees would not increase the level of flood protection. The maximum flood plain acreage for this area is probably about 10,000 acres, but is dependent on breach location, peak flood stage, flood duration, and other factors. The area is predominantly agricultural and includes about 90 structures, primarily residences and agricultural structures. About 210 people reside in the potential flood plain. The first cost for the proposed reconstruction work in this area is about $920,000, or about $80,000 annually.

The flood hazard area for RD 1601, Twitchell Island, also has a benefit-to-cost ratio less than 1.0, based on non-Federal levees which are likely to fail below the design of Federal levees. Repairing the Federal levees alone would not increase the level of flood protection. The maximum flood plain acreage for this area is probably about 3,500 acres, but is dependent on breach location, peak flood stage, flood duration, and other factors. The area is predominantly agricultural and includes about 22 structures, primarily residences and agricultural structures. About 40 people reside in the potential flood plain. The first cost for the proposed reconstruction work in this area is about $7.9 million, or about $720,000 annually.

The flood hazard area which includes Brannan-Andrus Island Levee Maintenance District (RDs 317, 407, and 2607) and RD 556, Andrus Island, has a computed benefit-to-cost ratio significantly less than 1.0, based on estimated without-project annual damages of $2 million and annual costs for Federal levees of about $2.1 million. This area is also subject to failure of non-Federal levees on Twitchell Island which also could cause the area to flood. Costs to repair the non-Federal levees and bring them up to the design level of the Federal levees are not included. This area, which is completely encircled by levee embankments, contains about 15,000 acres, including the town of Isleton and agricultural lands. The area includes about 1,440 residences and commercial, public, and farm structures and about 2,060 people. Even if all potential flood damages could be eliminated with the reconstruction work proposed, the benefits would only support about $4 million in work. The first cost for the proposed reconstruction work in this area is about $22.5 million, or about $2.05 annually.

The flood hazard area for RD 349, Sutter Island, has a computed benefit-to-cost ratio greater than 1.0. This area, which is completely encircled by levee embankments, contains about 2,500 acres, predominantly agricultural. The area includes about 90 structures (residences and farm structures) and about 140 people. Estimated average annual flood damages under without-project conditions are about $325,000 (see section on Economics). The first cost for the proposed reconstruction work in this area is about $294,000, or about $30,000 annually.

The flood hazard area for RD 150, Merritt Island, has a benefit-to-cost ratio greater than 1.0. The maximum flood plain acreage for this area is probably about 4,700 acres, but is dependent on breach location, peak flood stage, flood duration, and other factors. The area is predominantly agricultural and includes about 160 structures, primarily residences and agricultural structures. About 230 people reside in the potential flood plain. Estimated average annual flood damages under without-project conditions are about $300,000. The first cost for the proposed reconstruction work in this area is about $216,000, or about $20,000 annually.

The flood hazard area which includes RD 501, Ryer Island, has a computed benefit-to-cost ratio less than 1.0. This area, which is completely encircled by levee embankments, contains about 12,000 acres, predominantly agricultural. The area includes about 130 residences and farm structures and about 200 people. Estimated average annual flood damages under without-project conditions are about $450,000. Even if all potential flood damages could be eliminated with the reconstruction work proposed, the benefits would only support about $790,000 in work. The first cost for the proposed reconstruction work in this area is about $1.5 million, or about $140,000 annually.

For the flood hazard area RD 3, Grand Island, the benefit evaluations indicate that this area is economically justified. RD 3 includes about 17,000 acres, mostly agricultural; about 400 structures, primarily residences and farm structures; and about 850 people. Estimated average annual damages under without-project conditions are about $2.2 million. The first cost for the proposed reconstruction work is about $1.7 million, or $150,000 annually.

The flood hazard area which includes RD 999, The Big Area, has a computed benefit-to-cost ratio significantly greater than 1.0. This area, which is completely encircled by levee embankments, contains about 33,000 acres, which are predominantly rural. The area includes about 780 residences and farm structures and about 1,300 people. Estimated average annual flood damages under without-project conditions are about $2 million (see section on Economics). The first cost for the proposed reconstruction work in this area is about $245,000, or about $20,000 annually.

The flood hazard area for Maintenance Area 9, Hood Area, has a benefit-to-cost ratio less than 1.0, based on non-Federal levees and embankments which are likely to fail at much a lower level than the Federal levees would fail, so the level of flood protection would not increase. Benefits cannot be claimed for the Hood Area because the Stone Lake area is another source of flooding. The Southern Pacific Railroad embankment provides a low level of flood protection to the Hood Area. A standard design levee would provide greater flood protection than is provided by the railroad embankment. The maximum flood plain acreage for this area is probably about 3,200 acres, but is dependent on breach location, peak flood stage, flood duration, and other factors. The area includes the town of Hood, some agricultural areas, and about 400 structures, primarily residences and agricultural structures with some commercial, public, and industrial structures. About 300 people reside in the potential flood plain. The first cost for the proposed reconstruction work in this area is about $6.5 million, or about $590,000 annually.

The flood hazard area which includes RD 536, South Lindsey Slough, has a computed benefit-to-cost ratio less than 1.0. This area, which has levee embankments on three sides and contains about 7,400 acres, is predominantly agricultural. The area includes about 74 residences and farm structures and about 87 people. Estimated average annual flood damages under without-project conditions are about $105,000. The first cost for the proposed reconstruction work in this area is about $800,000, or about $70,000 annually.

Table 10 also indicates that annual costs exceed annual benefits when the 13 flood hazard areas are aggregated. Current guidance restricts aggregation if the plan increments are functionally independent. In this evaluation, reconstruction work proposed for one flood hazard area to achieve design levels of flood protection is not functionally dependent on work proposed for another area. The incremental economic evaluation presented in the preceding paragraphs is appropriate based on current guidance.

Local agencies supporting reconstruction of the Sacramento River Flood Control Project levees have expressed concerns

TABLE 10

RECONSTRUCTION PLAN
ECONOMIC SUMMARY

Area of Interest	First Cost ($1,000)	Annual Cost ($1,000)	Annual Benefits ($1,000)	B/C Ratio
RD 2060 (Hastings Tract southeast of Hastings Cut)	2,087	190	20	0.1
RD 2104 (Peters Pocket)	8,346	760	10	0.01
RD 2098 and 2068 (Moore Tract)	10,798	980	80	0.1
RD 341 (Sherman Island)	914	80	*	<1
RD 1601 (Twitchell Island)	7,934	720	*	<1
BA LMD and RD 556 (Brannan-Andrus and Andrus Island)	22,456	2,050	350*	0.2
RD 349 (Sutter Island)	294	30	50	1.7
RD 150 (Merritt Island)	216	20	30	1.5
RD 501 (Ryer Island)	1,554	140	70	0.5
RD 3 (Grand Island)	1,673	150	450	3.0
RD 563 (Tyler Island)	6,670	610	*	<1
RD 999 (The Big Area)	245	20	160	8.0
MA 9 (Hood Area)	6,440	590	*	<1
RD 536 (S. Lindsey Slough)	808	70	30	0.4
	70,435	6,410	1,250	0.2

* Non-Federal levees can fail below current Federal levee level of protection (no benefit or increase in flood protection).

^ Value of flooded area damage is much less than reconstruction cost.

NOTE: Does not include Cache Creek, Willow Slough Bypass, or Putah Creek which have no Federal interest under this authority due to deficiencies caused possibly by ground-water pumping.

regarding incremental analysis in determining Federal interest. In the Lower Sacramento Area phase of the Sacramento River Flood Control System Evaluation, 10 of the 14 flood hazard areas are <u>not</u> economically justified based on an incremental analysis. Table 11 summarizes the 4 of the 14 flood hazard areas which are economically justified based on an incremental analysis. This analysis does not include Cache Creek, Willow Slough Bypass, and Putah Creek, as deficiencies are not design deficiencies.

TABLE 11

RECONSTRUCTION PLAN
ECONOMIC SUMMARY
INCREMENTALLY FEASIBLE AREAS

Area of Interest	First Cost ($1,000)	Annual Cost ($1,000)	Annual Benefits ($1,000)	B/C Ratio
RD 349 (Sutter Island)	294	30	50	1.7
RD 150 (Merritt Island)	216	20	30	1.5
RD 3 (Grand Island)	1,673	150	450	3.0
RD 999 (The Big Area)	245	20	160	8.0
Total	2,428	220	690	3.1

The local agencies, including the potential non-Federal sponsor, The Reclamation Board, contend that economic justification and subsequent Federal interest should be based on a systems evaluation. Their rationale is based on the fact that the Congressionally authorized Sacramento River Flood Control Project was justified by total system benefits. In addition, the State contends that the project was turned over (to the State) for maintenance and operation as a total system. The systems evaluation compares total costs of reconstructing all levees of the Sacramento River Flood Control Project and total benefits attributable to that work. A Limited Reevaluation Report for a total system evaluation has been completed, indicating that the system is economically feasible. However, those areas that have been found to be incrementally infeasible are identified in the LRR. Current Corps policies allow only those areas that are incrementally justified to be recommended for Federal interest in reconstruction work.

RISK ASSESSMENT

About 6,000 people live in the flood hazard areas shown in Figure 44. The report by the California Department of Finance, "Total Population of California Cities January 1992 and 1993 with Percentage Change," shows a population of 870 in Isleton. The Rand McNally 1993 Commercial Atlas shows a population of 435 in Hood and 1,500 in Walnut Grove.

All the developed lands within the study area are protected by more than one levee embankment. In the Sacramento-San Joaquin Delta, Andrus, Brannan-Andrus, Sherman, Sutter, and Tyler Islands are completely surrounded by Federal and non-Federal levees.

Historic levee failures have resulted in significant property damage. On 19 February 1986, 9,583 acres on Tyler Island were flooded when a non-Federal levee broke on the Mokelumne River. Damages on Tyler Island at the time of the flood were estimated at $10.4 million. Fill material was placed on a road crown to prevent flooding of residential sections of the city of Walnut Grove. In 1986, floodfighting took place along Georgiana Slough on the Tyler Island side and along the Sacramento River at Clarksburg and Isleton.

A non-Federal levee on Brannan-Andrus Island broke shortly after midnight on 21 June 1972, flooding Andrus Island and parts of the adjoining Brannan Island, including about 35 percent of the city of Isleton. The levee failure was due to geotechnical instability at high tide during a time of no flooding; eventually the levee break reached a width of 500 feet. Total damages were estimated at $27 million (1972 dollars). About 2,000 residents of the area were evacuated. The residents returned to their homes on September 15. All pumping of floodwater from the island was completed by the end of 1972.

On January 20, 1969, a non-Federal levee on Sherman Island developed a massive crack which within a few minutes developed into a 300-foot-wide and 40-foot-deep levee break. Structures were flooded to depths of 4 to 5 feet and were a complete loss as a result of wind and wave action. State Highway 160 was inundated, and damages were estimated at $7 million (1967 dollars).

Population at Risk

A major adverse impact resulting from a levee failure within the study area is the potential for loss of human life. The extent of the impact depends on the location and magnitude of flooding, time of day, and warning time; flood fight efforts; and effective implementation of a flood evacuation plan. A preliminary assessment was made of potential loss of life should a levee fail during a major flood event. The assessment assumed the existence of a local evacuation plan developed in conjunction with a flood warning system. Based on the above and information contained in this report, the evacuation would probably be ordered 1 to 2 hours before a levee break. Because of the short warning period, only a small percentage of the people residing in a potential flooded area, probably between 10 and 20 percent, would be able (or choose) to evacuate in a timely manner. Because of the potential for deep depths of flooding, a levee failure in the vicinity of populated areas would probably result in loss of life, probably between 5 and 10 people.

Flood warnings are generally based on existing and projected flood stages in a specified levee reach. Normally, critical flood stages would be those that are at or near the design water surface (about 3 to 6 feet below the levee crown). Because of the potential modes of levee failure, instability, and piping, levee failures can and have occurred in and adjacent to the study area at flood stages that are 5 to 10 feet below the top of levee. In addition, levee failures can and have been rapid blowouts of levee embankment materials at the landside toe of the levee. Many of the islands in the Sacramento River Delta are below sea level (and thus below normal water level), which can result in high depths of inundation. Because of the above, a reasonable flood warning and evacuation plan would be difficult to develop and enforce. As such, loss of human life is expected under existing conditions (without reconstruction work) for major flood events.

Because public safety is a primary concern, there is potential justification for Federal interest in reconstruction work proposed in this study. In addition, local agencies should ensure that people residing in the flood hazard areas delineated in this report are aware of the flood threat during major flood events. Local agencies should also develop operational plans for flood warning and evacuation if plans do not exist already.

CHAPTER VI - DISCUSSION AND CONCLUSIONS

The levee embankments of the Sacramento River Flood Control Project were authorized to convey a specified flow with specified freeboard. These design criteria are used as a basis for levee embankment and channel maintenance and for the operation of upstream flood control storage facilities.

During the February 1986 flood, peak flood stages within the study area ranged from about 5 feet above the design water surface on Yolo Bypass to about 4 feet below the design water surface on Threemile Slough. Although no Federal project levees failed in the study area during the 1986 flood, a flood fight was needed at Clarksville on the Sacramento River due to wind generated wave erosion. Boils on Georgiana Slough and the Sacramento River were sandbagged. Failure of two non-Federal levees on Tyler Island necessitated flood fighting to prevent the city of Walnut Grove from being inundated. A flood fight was also required on a non-Federal levee on Brannan-Andrus Island to prevent the city of Isleton from being inundated.

Geotechnical evaluations and personnel responsible for the maintenance of project levees indicate that the primary concern related to levee embankment integrity is the susceptibility of embankment and foundation soils to seepage and piping. Since many of the islands in the Delta are below sea level and seepage occurs year round because the water levels are above the island ground levels, levees can fail at any time of the year, not just in flood season.

Recent levee crown surveys in the study area indicate that portions of levee reaches on Cache Creek, Willow Slough Bypass, Yolo Bypass, Cache Slough, Lindsey Slough, Haas Slough, Miner Slough, Georgiana Slough, Threemile Slough, and the Sacramento River do not have the necessary design freeboard above the design water surface. A comparison of the existing and design levee crown profiles and levee cross sections suggests slumping of the levee embankments in some areas, especially Georgiana Slough, the Yolo Bypass, and Threemile Slough. Because the foundation problems and subsidence in the Lower Sacramento Area are caused by peat, many of the levees that do not have design freeboard above the design water surface have had similar problems in the past and are likely to have similar problems in the future. Levee subsidence on Cache Creek and Willow Slough Bypass appears to have been caused by ground-water pumping.

To ensure that the design flow can be conveyed safely within the project levees at the design water surface, reconstruction work is recommended. The potential work would include about 34 miles of levee raising and 8.8 miles of landside berm with toe drain to meet minimum design freeboard requirements. This does not include 17.8 miles of levee raising needed on Cache Creek, the Willow Slough Bypass, and Putah Creek; deficiencies of these levees appear to be due to subsidence caused by ground-water pumping and/or other non-design deficiencies. These levees should be restored by The Reclamation Board. The total cost for the reconstruction work, excluding Cache Creek, Willow Slough Bypass, and Putah Creek, is about $70.4 million. Of this total, only $2.4 million is incrementally feasible.

In the Lower Sacramento Area, Phase IV of the Sacramento River Flood Control Project, portions of the Yolo Bypass and the Willow Slough Bypass cannot convey the design flow within the design water surface. The Reclamation Board is the local entity responsible for the maintenance and operation of the Sacramento River Flood Control Project, and it is The Reclamation Board's responsibility to ensure that the design flow can be conveyed safely within the design water surface (assuming that the levee embankments can convey the design flow without levee failure). Independent of the reconstruction work presented above, The Reclamation Board would be required to evaluate each of the levee reaches cited to determine causes of the design flow deficiencies and to develop measures for eliminating any deficiencies. To ensure that the design flow can be conveyed safely within the project levees at the design water surface, The Reclamation Board would be required to implement correction measures (such as dredging, clearing, levee modification, etc.) for these sites at their expense under existing operation and maintenance agreements.

With regard to design flow deficiencies, The Reclamation Board should ensure that encroachments, including land use changes, proposed within the project levee system be evaluated in detail. Because portions of Yolo Bypass and the Willow Slough Bypass cannot convey the design flow within the design water surface, any additional encroachment in these areas could adversely affect flood stages and the design condition due to the backwater effects or direct effect of conveyance capacity. Based on information in this report, encroachments should not be permitted within the Yolo Bypass downstream of Interstate 80 (as noted in the Mid-Valley Initial Appraisal Report) or in the lower reaches of the Willow Slough Bypass unless it can be shown that such encroachments do not adversely affect design conditions. Any encroachments that might be considered elsewhere in the study area should be evaluated to determine potential adverse impacts to those levee reaches which cannot convey the design flow within the design water surface.

Although there is always the question of adequate maintenance by the local agencies, the reconstruction work presented in this report is the result of internal soil conditions (within the levee embankment and subsurface foundation) and not inadequate maintenance.

In response to the Conference Report accompanying the Energy and Water Development Appropriation Act, 1987, the Corps of Engineers was directed to report on enhanced levels of flood protection which it encounters in the review of the project. Based on information presented in this report, the recurrence intervals associated with the February 1986 peak flood stages range between 20 and 100 years based on existing conditions and depending on location within the study area. With the implementation of the reconstruction work presented herein, higher levels of flood protection could be achieved (recurrence intervals would be equal to or greater than the 20 and 100 years cited). Enhanced levels of flood protection were examined in the "Sacramento-San Joaquin Delta, California, Special Study," March 1993. In addition, a reconnaissance study entitled "Westside Tributaries to Yolo Bypass, California," is being conducted for the west Yolo Bypass tributaries of Cache Creek, Willow Slough Bypass, and Putah Creek, and a Section 205 reconnaissance study is being completed for the city of Isleton on Brannan-Andrus Island.

The programmatic environmental impact statement and environmental impact report (EIS/EIR) for Phases II through V of the Sacramento River Flood Control System Evaluation has been filed with the Environmental Protection Agency.

CHAPTER VII - RECOMMENDATIONS

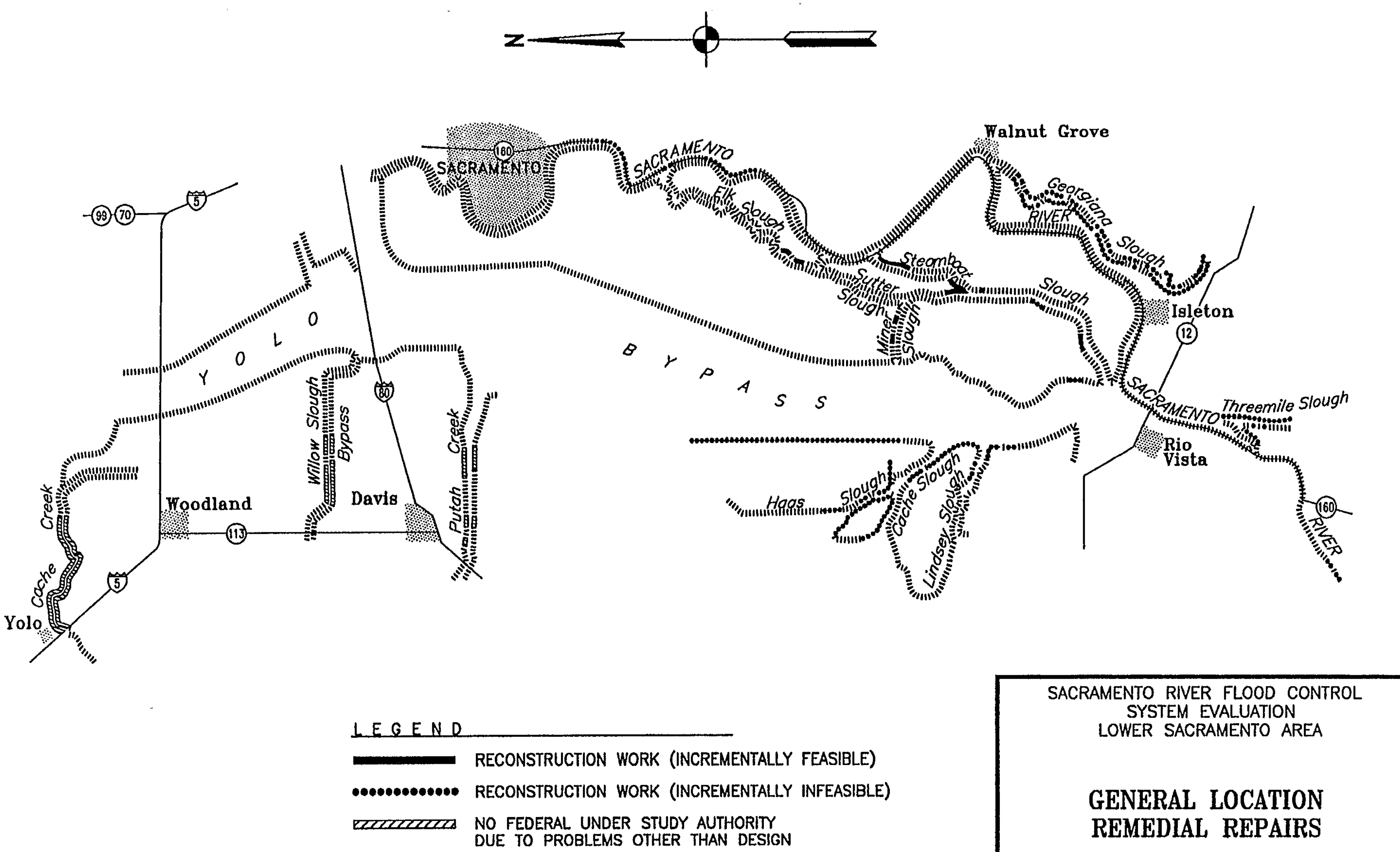
This Initial Appraisal Report for the Lower Sacramento Area, Phase IV of the Sacramento River Flood Control Project System Evaluation, is in response to the Energy and Water Development Appropriation Act, 1987, which directed the Corps of Engineers to evaluate the integrity of the Sacramento River Flood Control Project system. This report covers Phase IV of the system evaluation.

This report evaluates about 295 miles of project levees along parts of the lower Sacramento River, Yolo Bypass, and various tributaries and distributaries. This study area covers portions of Sacramento, Solano, and Yolo Counties.

Studies indicate that sections of the project levees are susceptible to seepage and stability problems and/or lack the authorized levee height to safely provide the design levels of flood protection approved by Congress. Potential problems are primarily the result of poor levee embankment material and foundations. About 47 miles of levee reconstruction is required to meet project design requirements. The total estimated cost of the reconstruction plan is about $70.4 million; local contribution would be about $17.5 million. About 6,000 people reside landward of the levees that need repair; damageable properties in those areas is estimated at $440 million. The plan does not include reconstruction work on about 18 miles of levees on Cache Creek, the Willow Slough Bypass, and Putah Creek as the levee crown deficiencies in these areas appear to be caused by subsidence due to ground-water withdrawal or possibly a combination of non-design effects.

Only a portion of the total reconstruction work required is economically justified and has a benefit-to-cost ratio greater than one based on current guidance regarding incremental analysis. The justified work includes RD 349 (Sutter Island), RD 150 (Merritt Island), RD 999 (Big Area), and RD 3 (Grand Island), as shown on Figure 74, and costs about $2.4 million (see Table 11).

As required, a system evaluation of all phases of the Sacramento River Flood Control Project System Evaluation has been performed as a Limited Reevaluation Report. This Limited Reevaluation Report shows that the total system has a feasible benefit-to-cost ratio in spite of a number of incrementally infeasible areas. Support by The Reclamation Board for a total system approach, regardless of any infeasible increments, is based on the justification that Congress authorized the Sacramento River Flood Control Project based on total benefits and costs. The Reclamation Board also contends that the project was turned over to The Reclamation Board for maintenance and



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

GENERAL LOCATION REMEDIAL REPAIRS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 74

C-103488

operation as a total system. In addition, The Reclamation Board indicates that upstream flood control storage facilities constructed after 1940 were economically justified and are currently operated by various Federal, State, and local agencies under the assumption that the project levees can and have always been able to safely convey the design flow at the design water surface. Others have also shown interest and support for The Reclamation Board's position that reconstruction of the levees should be justified by a system approach.

By letter dated April 5, 1990 (see Attachment A), The Reclamation Board has indicated the intent to be the local sponsor for reconstruction work for the Lower Sacramento Area, Phase IV. The Reclamation Board is willing to participate with the Corps of Engineers in the reconstruction plan in accordance with Section 103(a) of the Water Resources Development Act of 1986.

The Sacramento District recommends proceeding with engineering and design studies for reconstruction in a manner generally consistent with the work allowance instructions for Fiscal Year 1993 and review comments on the Mid-Valley Area IAR. These studies would include the preparation of a Design Memorandum on <u>all</u> levee sections included in the IAR. Plans and specifications would only be prepared for incrementally feasible areas unless a PCA is executed to include incrementally infeasible levee sections identified in the IAR. Similarly, the District will budget for reconstruction only for incrementally feasible areas.

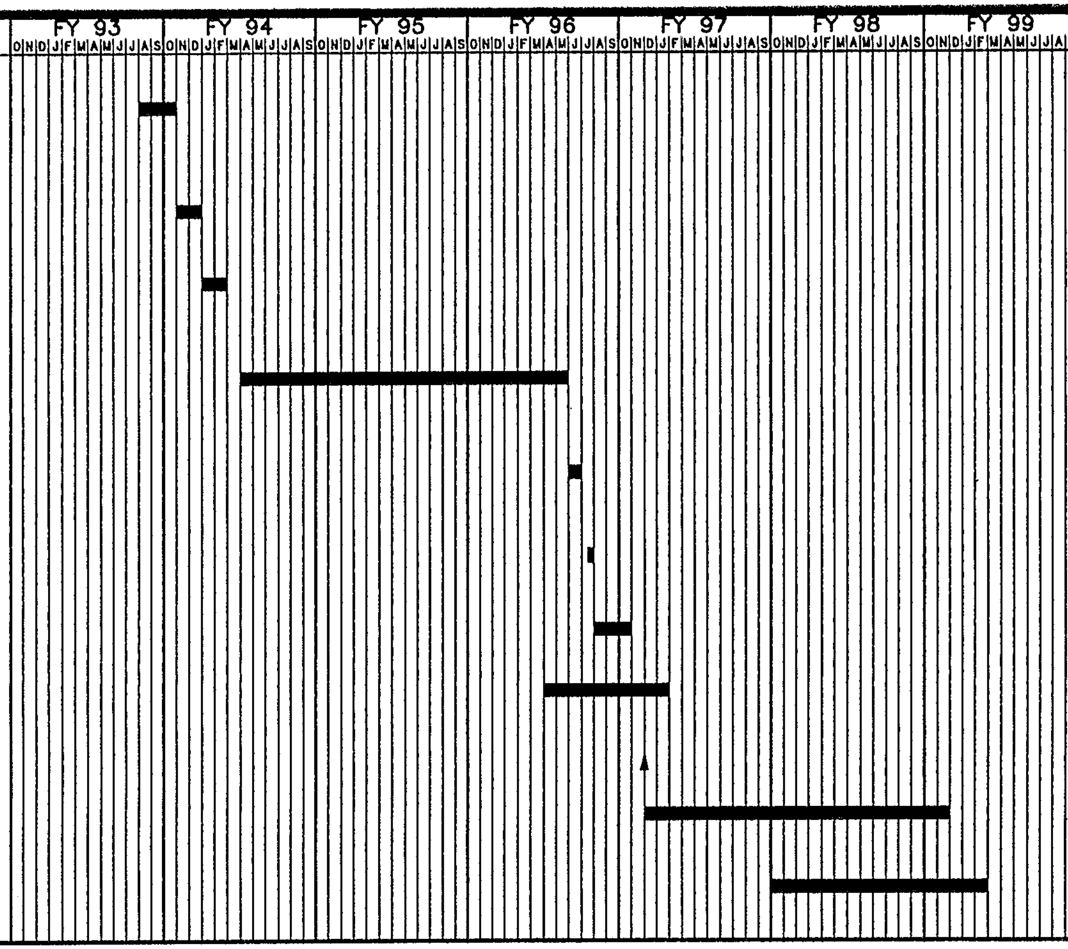
Some areas are protected by non-Federal levees which have not been certified as providing levels of protection equal to or greater than the levels provided by the Federal levees. Prior to Federal reconstruction of levees in those areas (that is, Sherman, Tyler, and Twitchell Islands and part of Maintenance Area 9), The Reclamation Board should evaluate the non-Federal levees and raise them to levels of protection equal to or greater than the Federal levees in order to provide benefits for reconstruction work on the Federal levees. Reconstruction work required to meet design criteria but that is <u>not</u> incrementally feasible (see Figure 75) could be eliminated from further Federal consideration. Study results included in this report could be used as a guide to implement any additional reconstruction work that non-Federal interests might support in areas where non-Federal levees also protect areas with Federal levees.

In addition to the reconstruction work indicated above, the following actions are needed:

- The Reclamation Board should evaluate levees on Cache Creek, the Willow Slough Bypass, and Putah Creek to determine current levee crown elevations with corrections for survey

C-103489

ITEM	PERTINENT DATES
REVISED INITIAL APPRAISAL REPORT (IAR) W/ENVIRONMENTAL EVALUATION	
SPD REVIEW IAR	SPD APPROVE IAR, JAN. 1993
HQUSACE REVIEW/APPROVAL	SPD APPROVE USE CG FUNDS MARCH 1994
DESIGN MEMORANDUM (DM) W/ENVIRONMENTAL ASSESSMENT (EA)	SUBMIT DM/EA TO SPD JUNE 1996
SPD REVIEW DM	
HQUSACE REVIEW/APPROVE DM & PCA	
ASA(CW) REVIEW/APPROVE DM & PCA	
PLANS & SPECIFICATIONS (P&S)	INITIATE P&S, CONTRACT 1 APRIL 1996
SIGN PCA	SIGN PCA, DEC. 1996
REAL ESTATE ACQUISITION	INITATE NEW CONSTRUCTION START, DEC. 1996 (ACQUIRE LANDS)
CONSTRUCTION	AWARD FIRST CONTRACT, SEPTEMBER 1997



SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
LOWER SACRAMENTO AREA

SCHEDULE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

FIGURE 75

errors which may be caused by the regional subsidence. Subsidence impacts on the flood control system due to ground-water pumping should be studied by The Reclamation Board to ensure the system can and will operate as designed. As part of their operation and maintenance responsibilities, if all levee deficiencies are indeed caused by ground-water pumping, The Reclamation Board should restore the levees to safely pass the design flows at the design elevation plus freeboard.

- Revise the Sacramento River Flood Control Project operation and maintenance manual to define procedures for the non-Federal sponsor to install flood barriers at specified railroad and road crossings and other depressed areas of the levee embankment crown. Detailing locations where flood barriers need to be installed would assist in ensuring that the design flow can be conveyed safely within the project levees at the design water surface.

- The Reclamation Board should permanently fill specified localized depressed areas of the levee embankment crown rather than use temporary flood barriers. The depressed areas are generally located at abandoned railroad crossings and where there is continual cross traffic.

- The Reclamation Board should evaluate in detail the project levee reaches identified herein with design flow deficiencies, to determine causes of the design flow deficiencies, and to develop measures for eliminating any deficiencies. The Reclamation Board should also evaluate levee reaches where deficiencies are due to nondesign causes (i.e., ground-water pumping) and develop measures to eliminate these deficiencies. Corrective measures would be implemented at the non-Federal sponsor's expense under existing Sacramento River Flood Control Project operation and maintenance requirements.

It should also be noted that several incrementally infeasible areas appear to have excellent potential for development of environmental mitigation/restoration areas. The flood control capacity of the Yolo Bypass could possibly be increased and possible hydraulic mitigation for flood control projects in the Sacramento River System could be achieved by removing or setting back project levees on Moore Tract (RD 2098 and RD 2068) and Peters Pocket (RD 2104). Wetlands, palustrine, shaded aquatic, and other valuable habitat could be developed on the tracts.

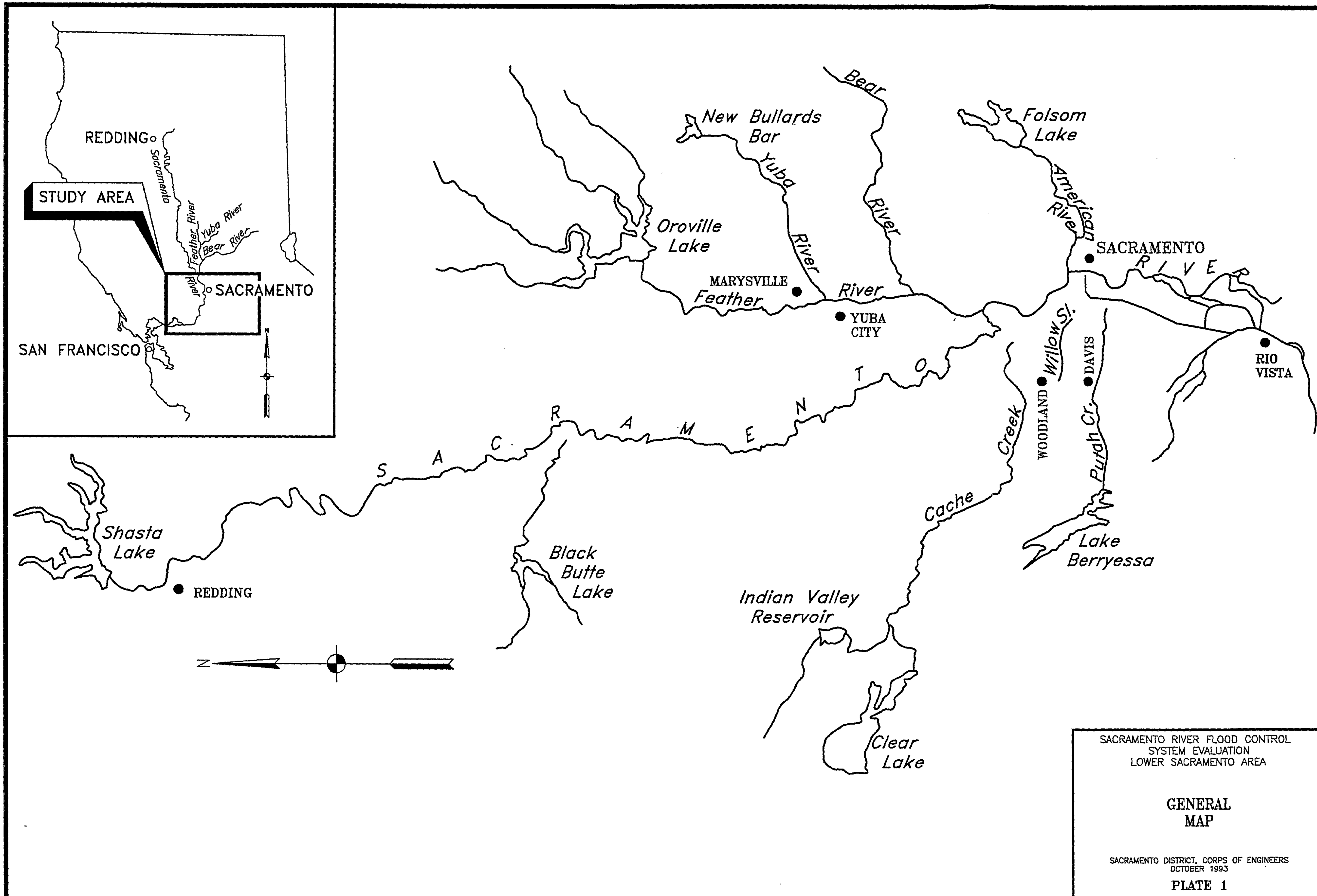
The Sacramento District recommends using this Initial Appraisal Report for obtaining approval to proceed with engineering and design studies using Construction General (CG) funds. Only feasible areas would be budgeted for reconstruction.

Use of CG funds would permit completion of a DM in FY 96 as shown by the schedule on Figure 75. The DM would be the PCA support document and would position the Sacramento District for a new construction start in FY 97.

The local sponsor, The Reclamation Board, has indicated a willingness and has initiated efforts to program the necessary local funds and staff to meet the schedule shown on Figure 75.

The recommendations contained herein reflect the information available at this time and current policies governing formulation of individual projects. They neither reflect program and budgeting priorities inherent in the formulation of a national Civil Works construction program nor the perspective of higher review levels within the Executive Branch. Consequently, the recommendations may be modified before they are transmitted to Congress as proposals for authorization and implementation funding.

PLATES



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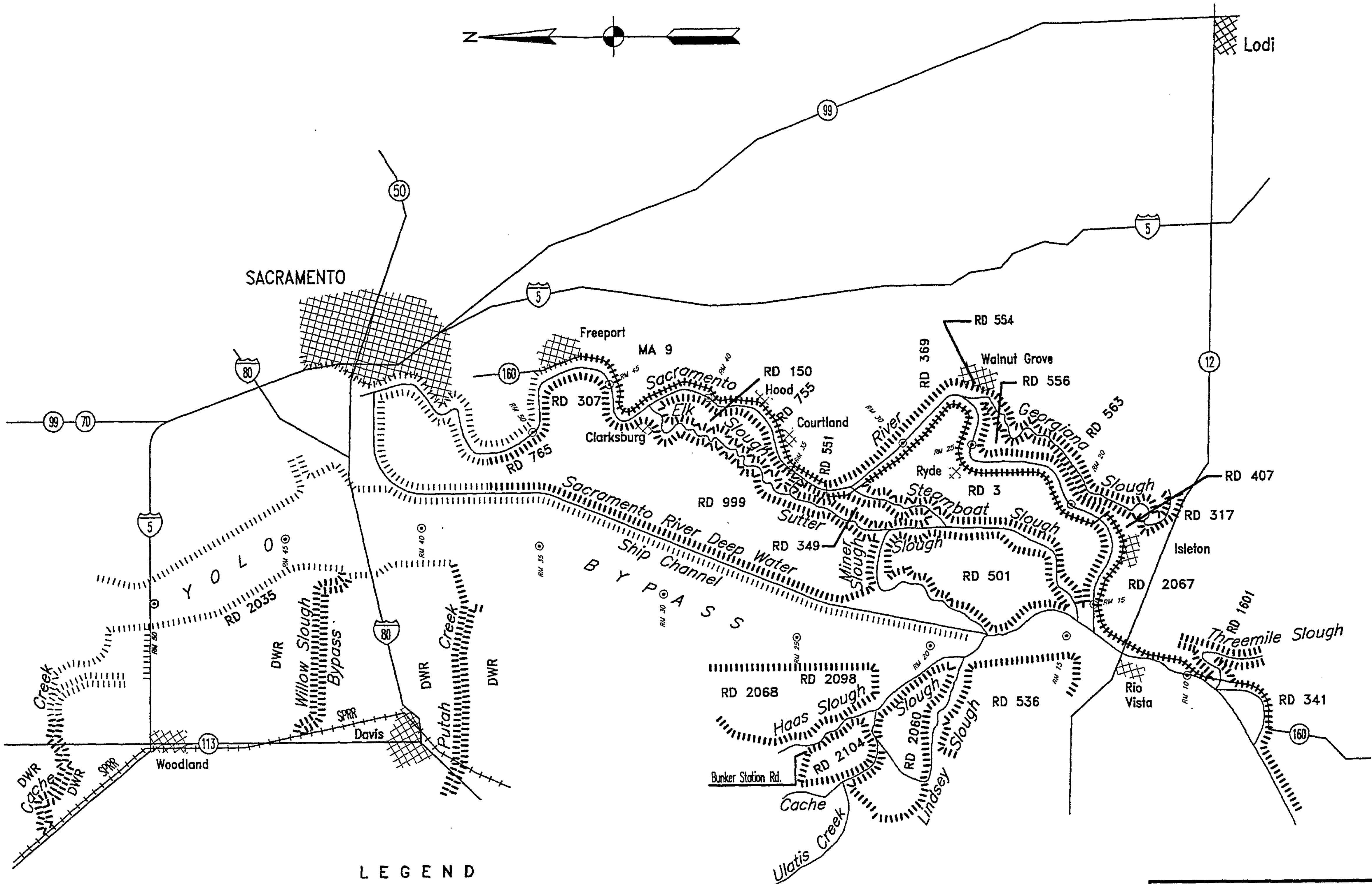

LEGEND

ııııııııııııııı	EXTENT OF LEVEE EVALUATION
ııııııııııııııı	LEVEES NOT EVALUATED
RD	RECLAMATION DISTRICT
MA	MAINTENANCE AREA
DWR	DEPARTMENT OF WATER RESOURCES
⊙ RM 0	CHANNEL OR RIVER MILES

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

STUDY AREA

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 2

C-103495

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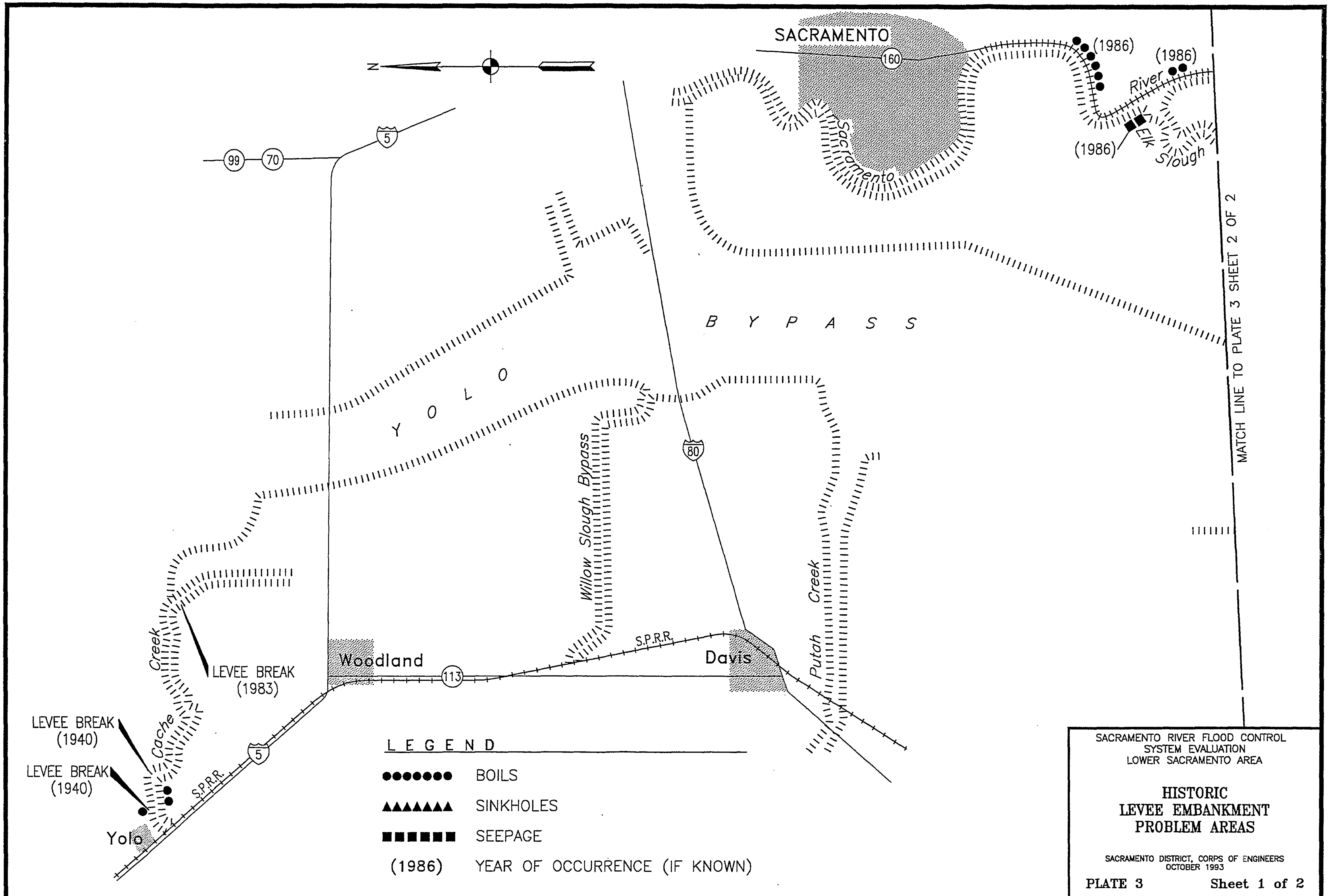
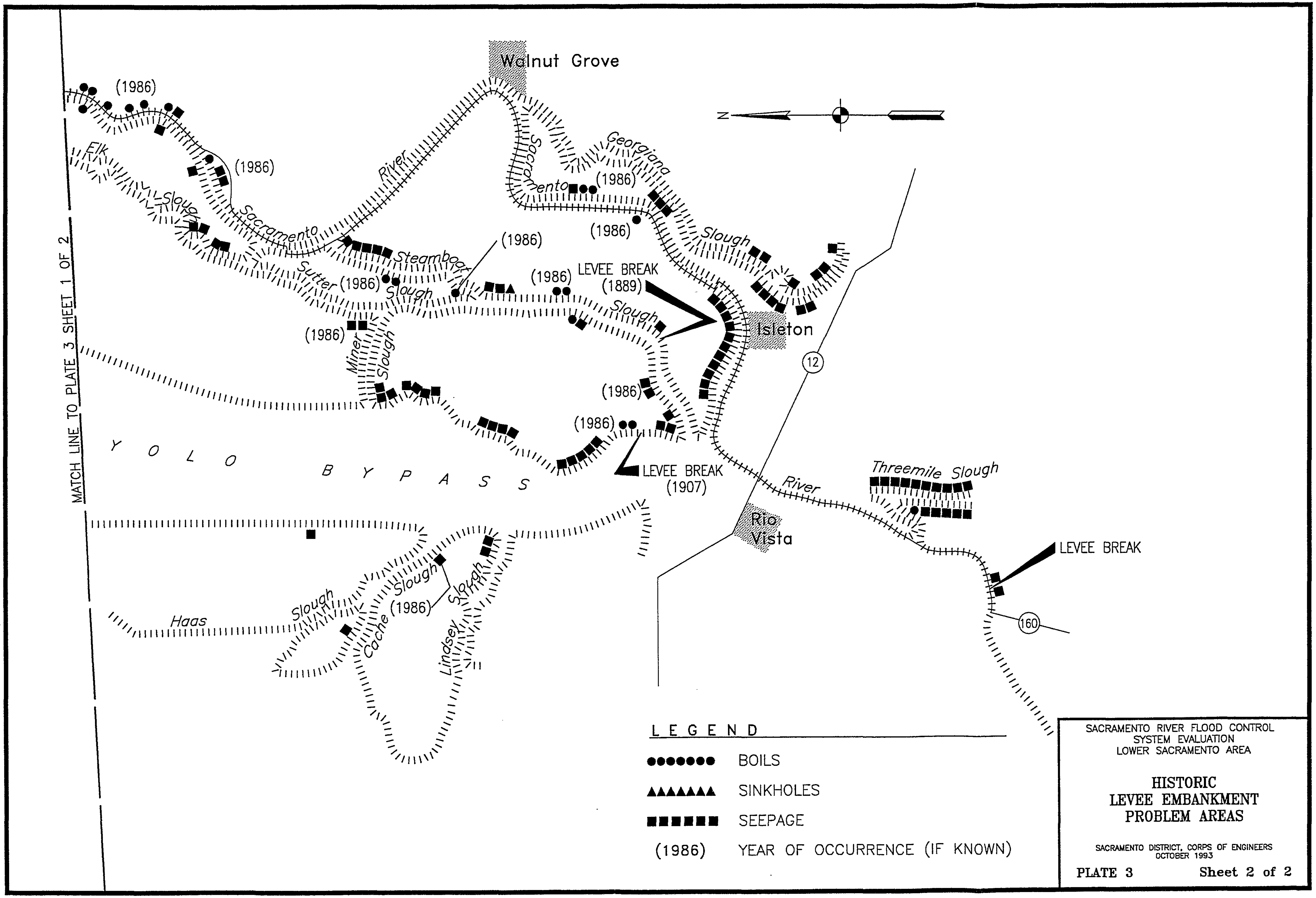


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

HISTORIC LEVEE EMBANKMENT PROBLEM AREAS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 3 **Sheet 1 of 2**



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

HISTORIC LEVEE EMBANKMENT PROBLEM AREAS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 3 **Sheet 2 of 2**

C-103497

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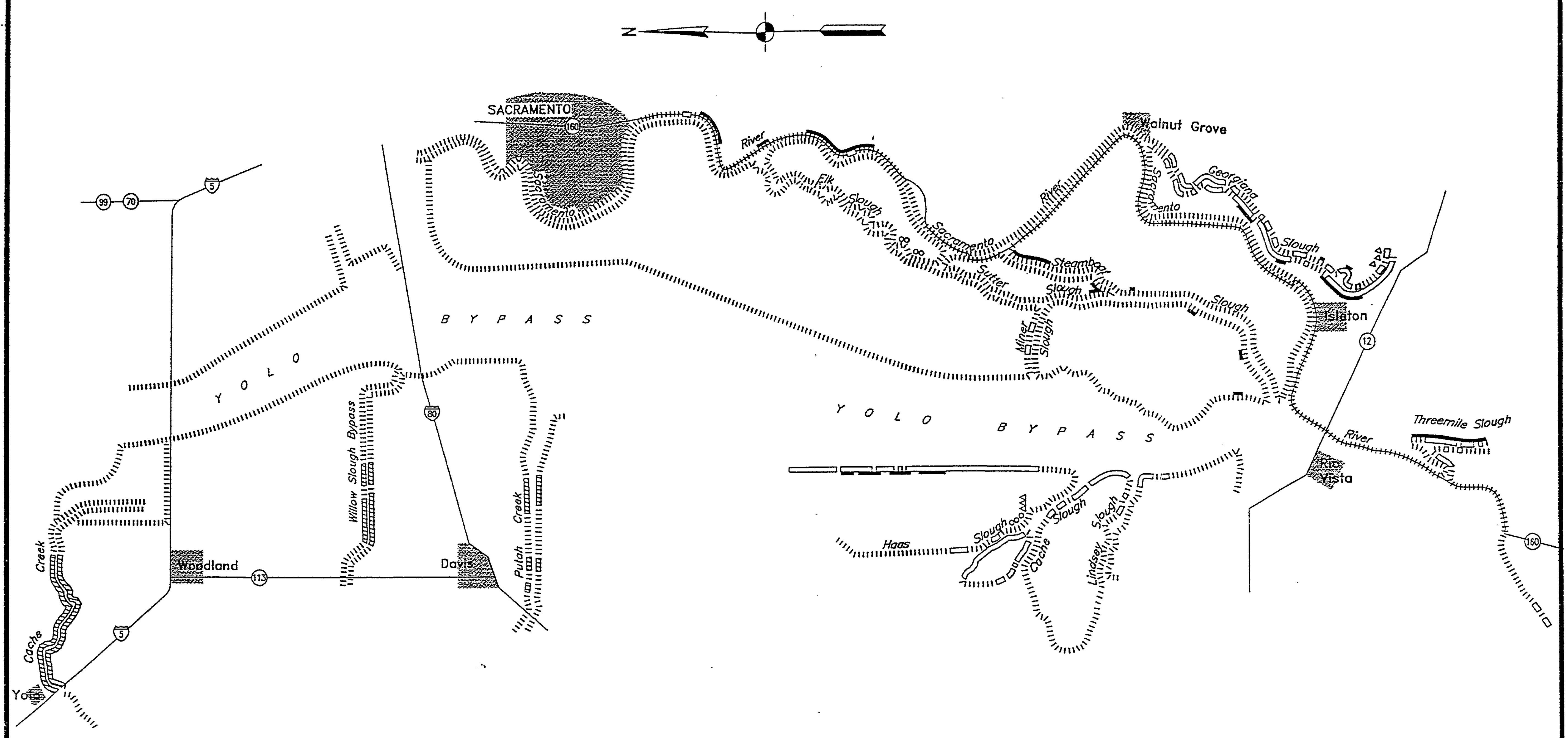


LEGEND

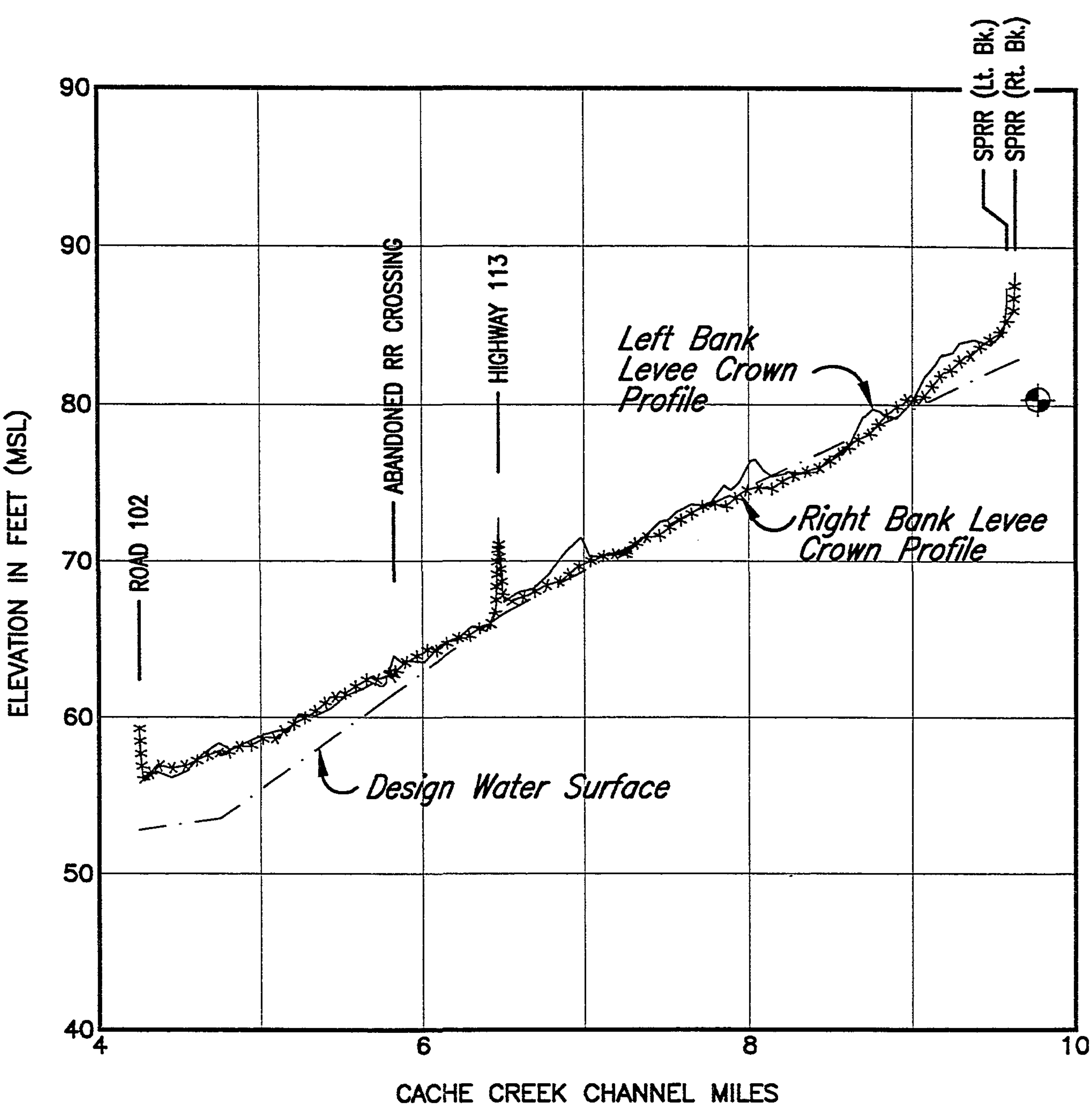
- LEVEE RAISING
- LANDSIDE BERM CONSTRUCTION
- DITCH RELOCATION
- DRAINAGE SYSTEM
- LEVEE RAISING DUE TO POSSIBLE SUBSIDENCE BY GROUND WATER PUMPING (NO FEDERAL INTEREST)

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
LOWER SACRAMENTO AREA

GENERAL LOCATON LEVEE RECONSTRUCTION

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 4 Sheet 1 of 1



LEGEND

HIGH WATER MARK (FEBRUARY 1986)

STAGE RECORDER READING (FEBRUARY 1986)

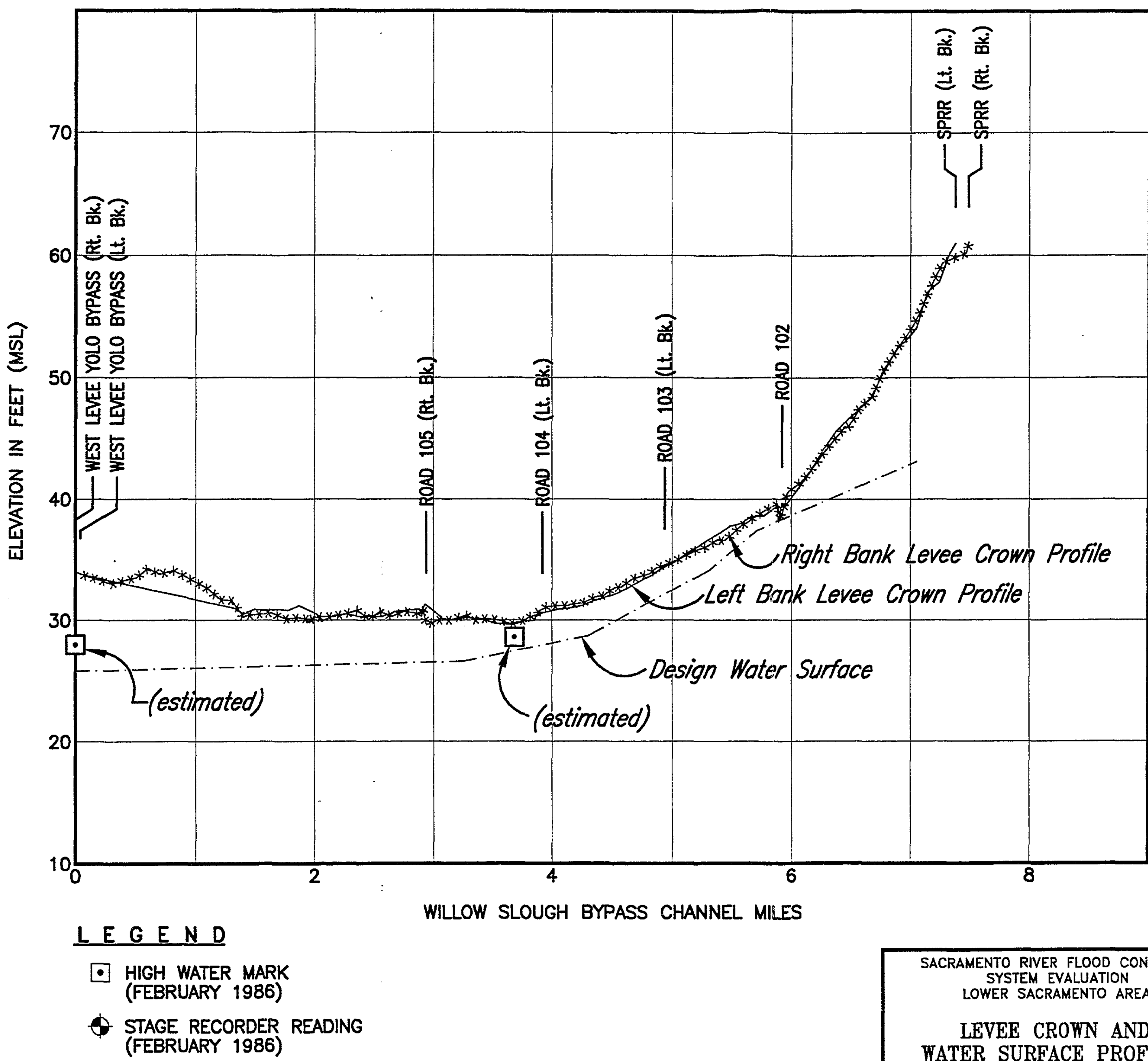
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND
WATER SURFACE PROFILES

CACHE CREEK

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 5 Sheet 1 of 1



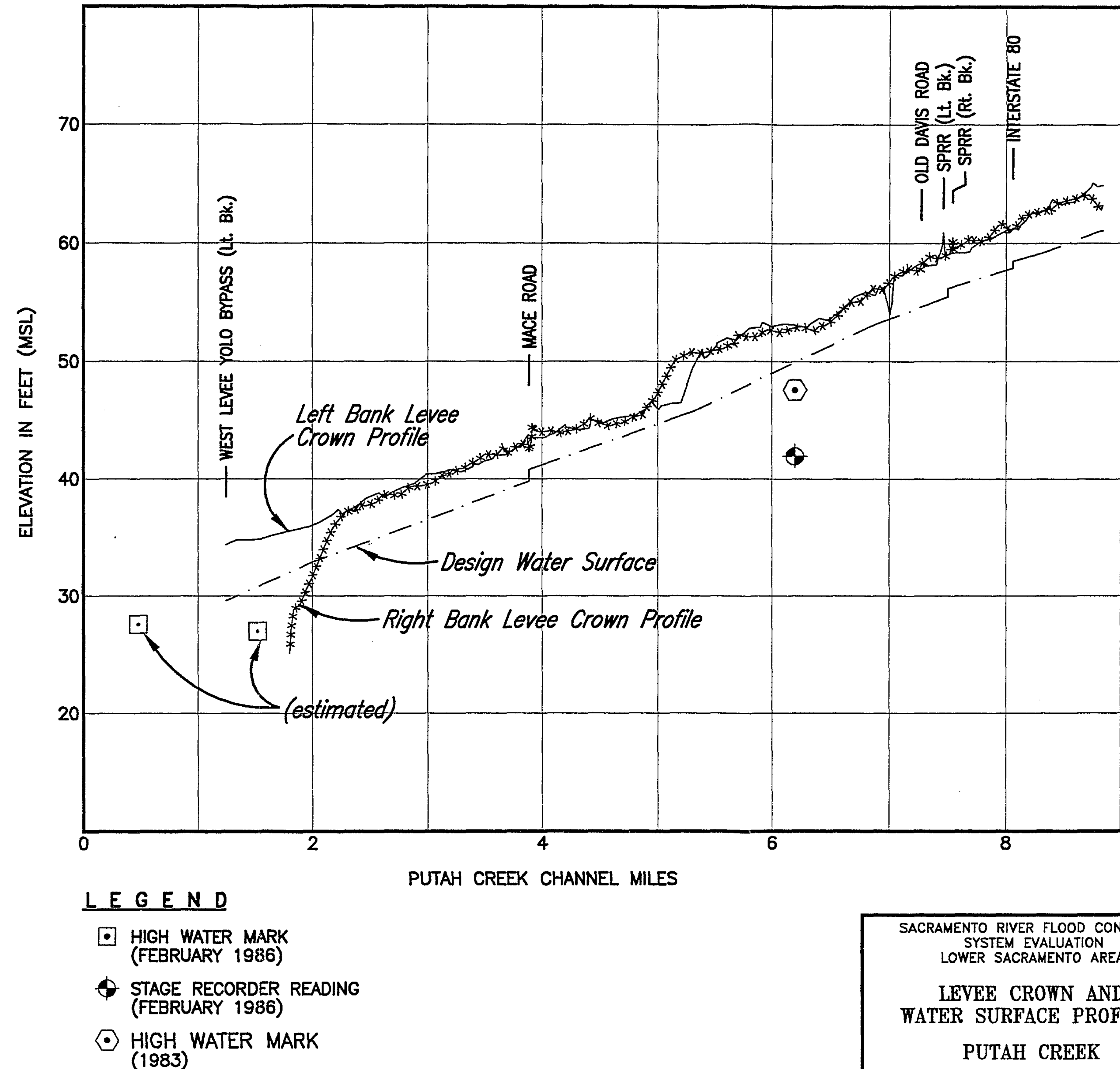
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND
WATER SURFACE PROFILES

WILLOW SLOUGH BYPASS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 6 Sheet 1 of 1



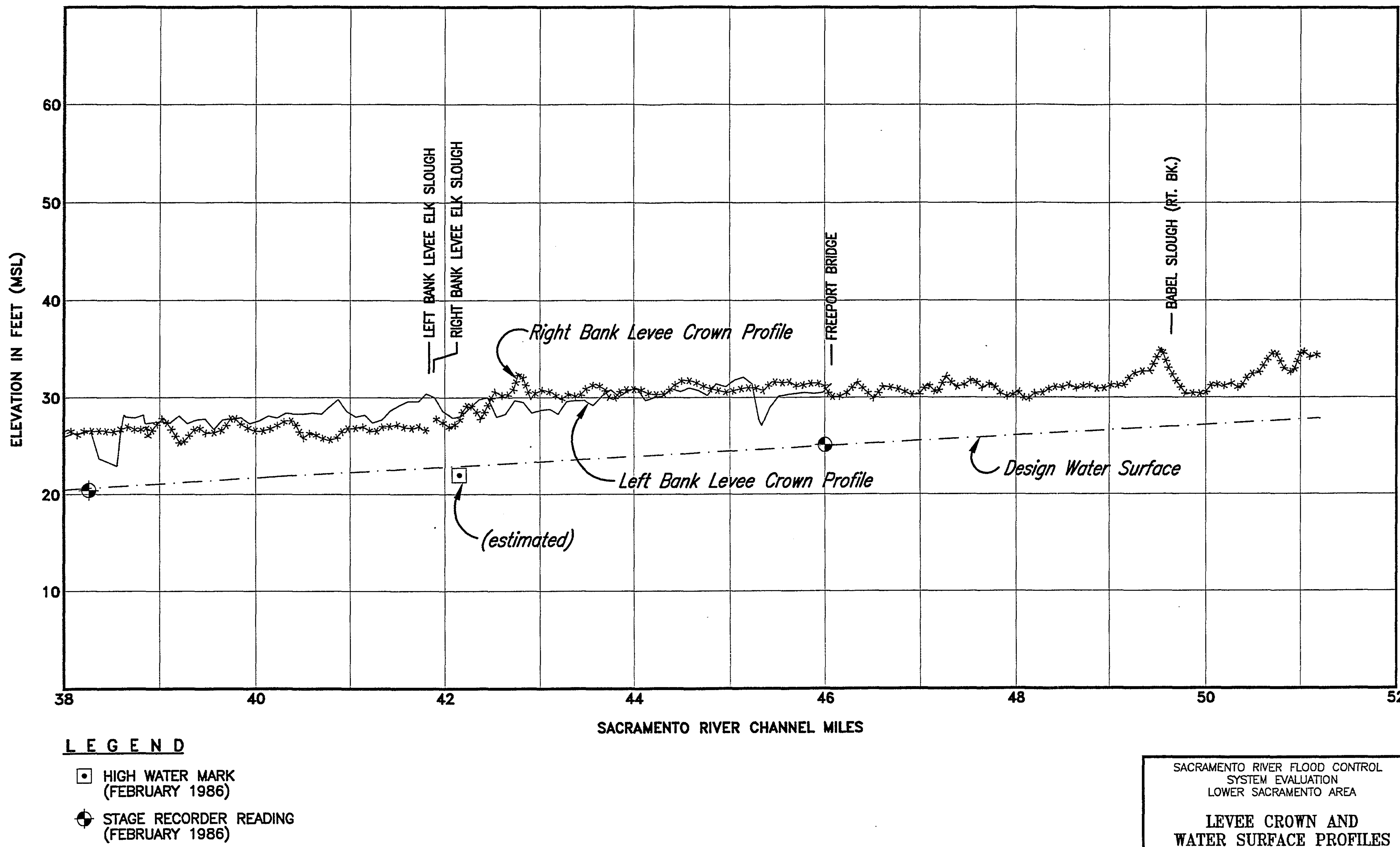
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND
WATER SURFACE PROFILES

PUTAH CREEK

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 7 Sheet 1 of 1



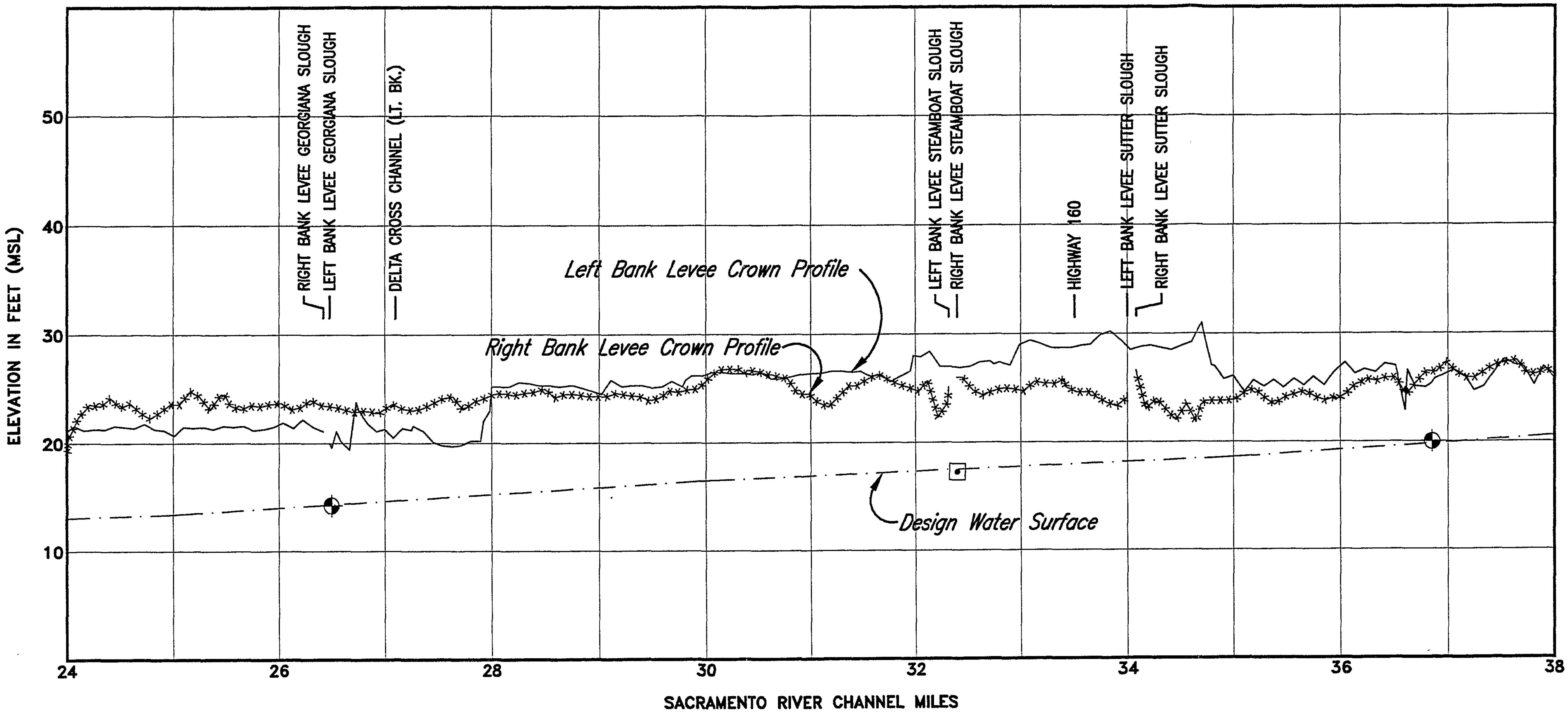
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND
WATER SURFACE PROFILES

SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 8 Sheet 1 of 4



LEGEND

HIGH WATER MARK (FEBRUARY 1986)

STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
LOWER SACRAMENTO AREA

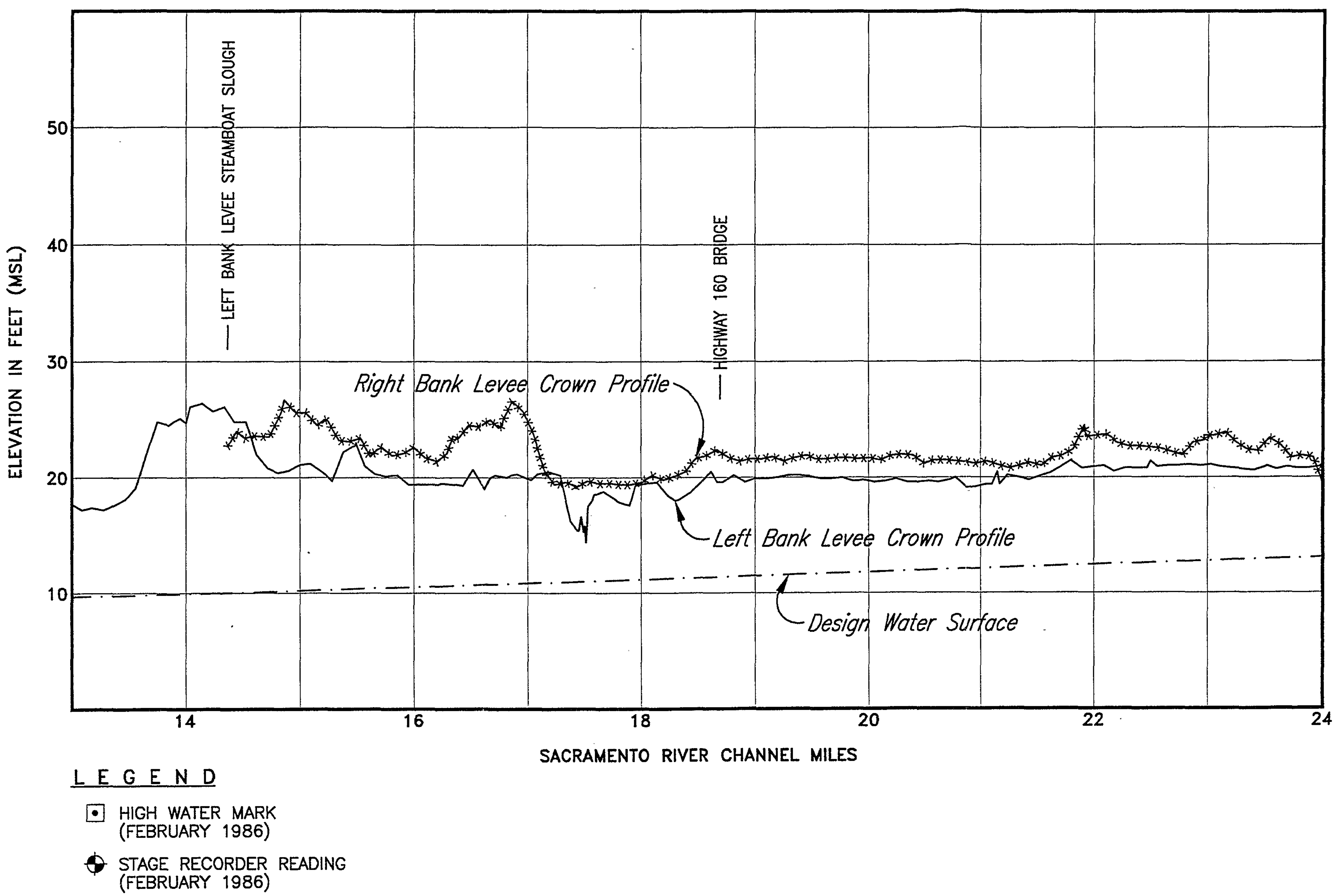
LEVEE CROWN AND WATER SURFACE PROFILES

SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 8 Sheet 2 of 4

C-103503



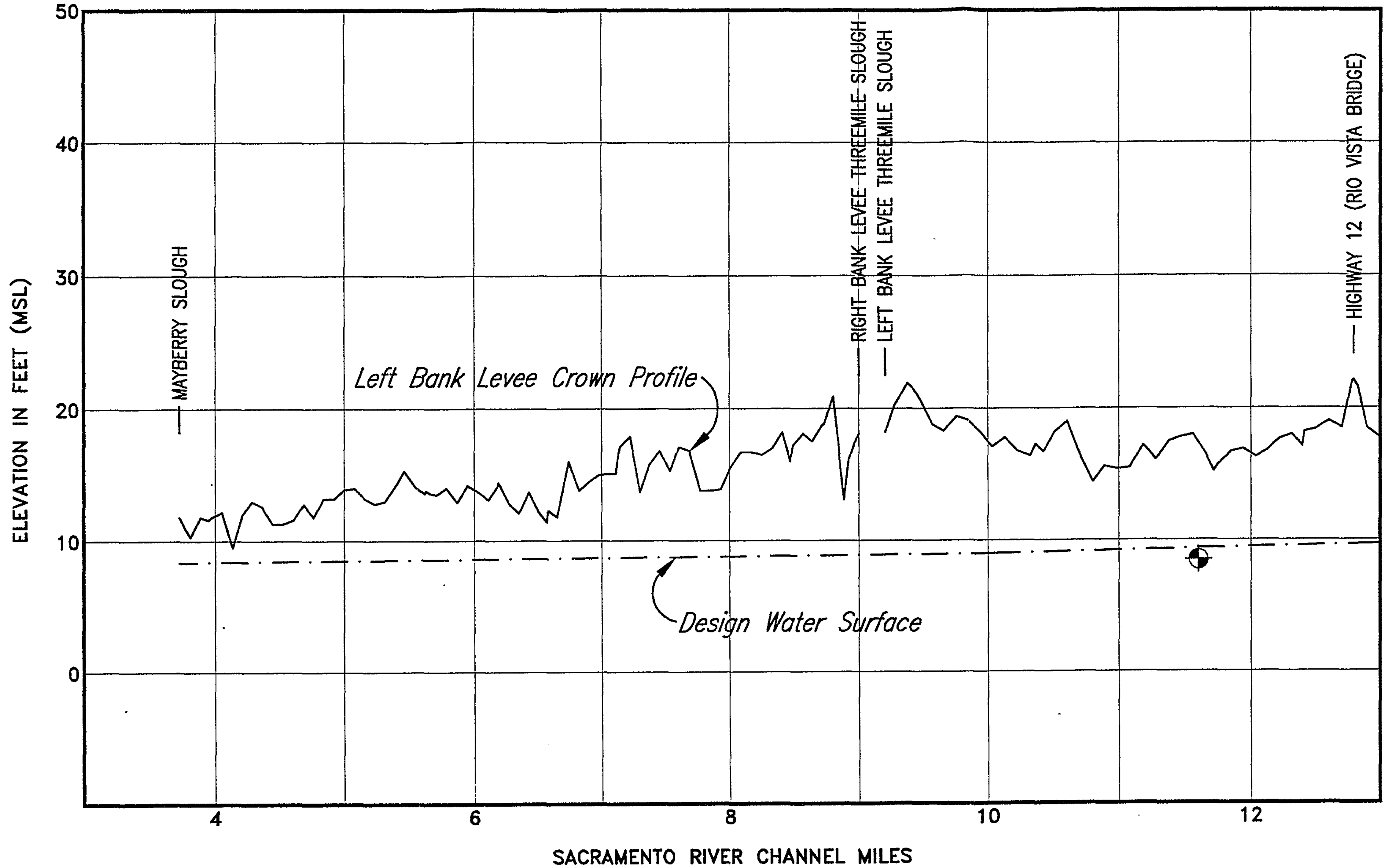
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND WATER SURFACE PROFILES

SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 8 **Sheet 3 of 4**



LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

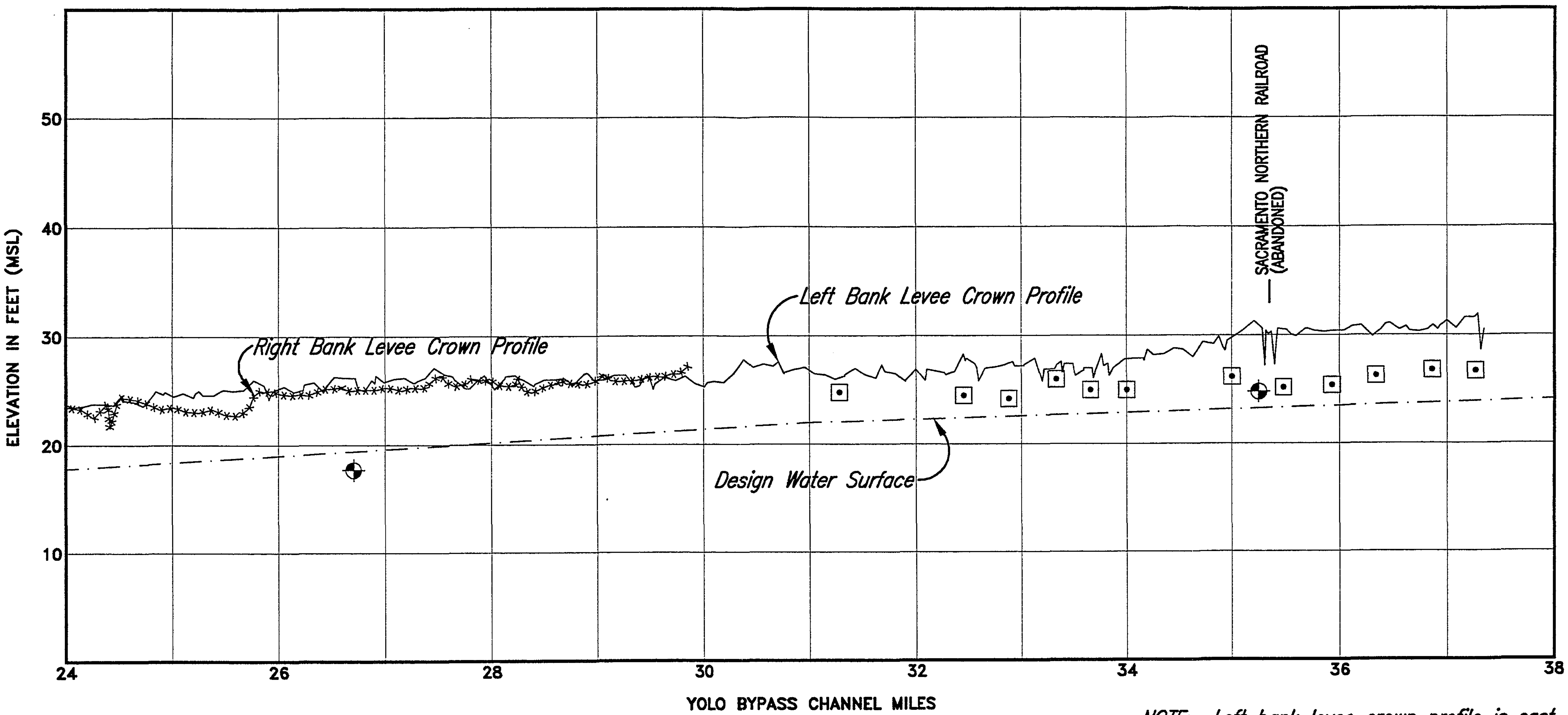
LEVEE CROWN AND WATER SURFACE PROFILES

SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 8 **Sheet 4 of 4**

C-103505



L E G E N D

HIGH WATER MARK (FEBRUARY 1986)

STAGE RECORDER READING (FEBRUARY 1986)

NOTE: Left bank levee crown profile is east levee of the Sacramento River Deep Water Ship Channel.

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
LOWER SACRAMENTO AREA

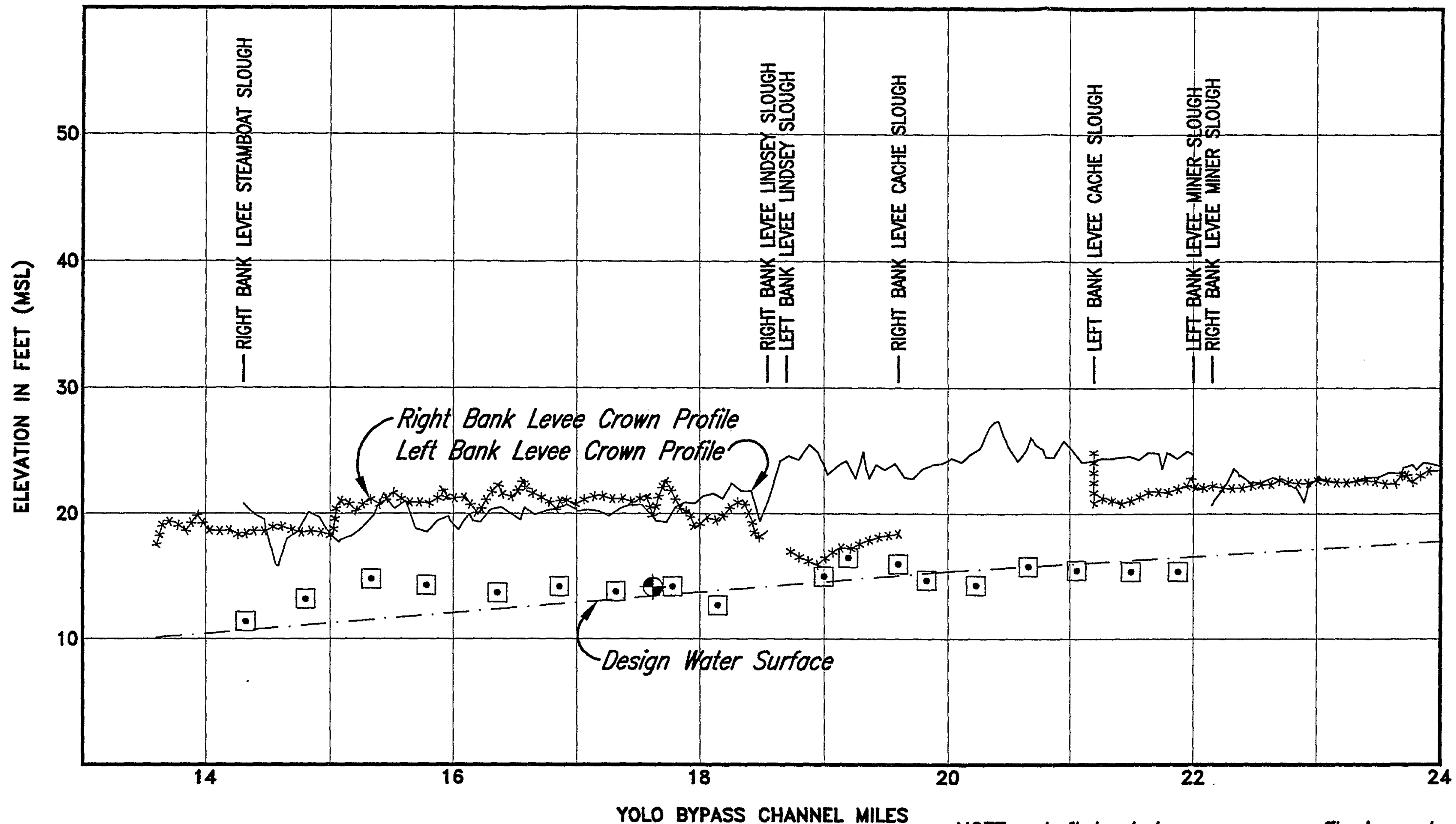
LEVEE CROWN AND WATER SURFACE PROFILES

YOLO BYPASS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 9 Sheet 1 of 2

C-103506



LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

NOTE: Left bank levee crown profile is east levee of the Sacramento River Deep Water Ship Channel.

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND WATER SURFACE PROFILES

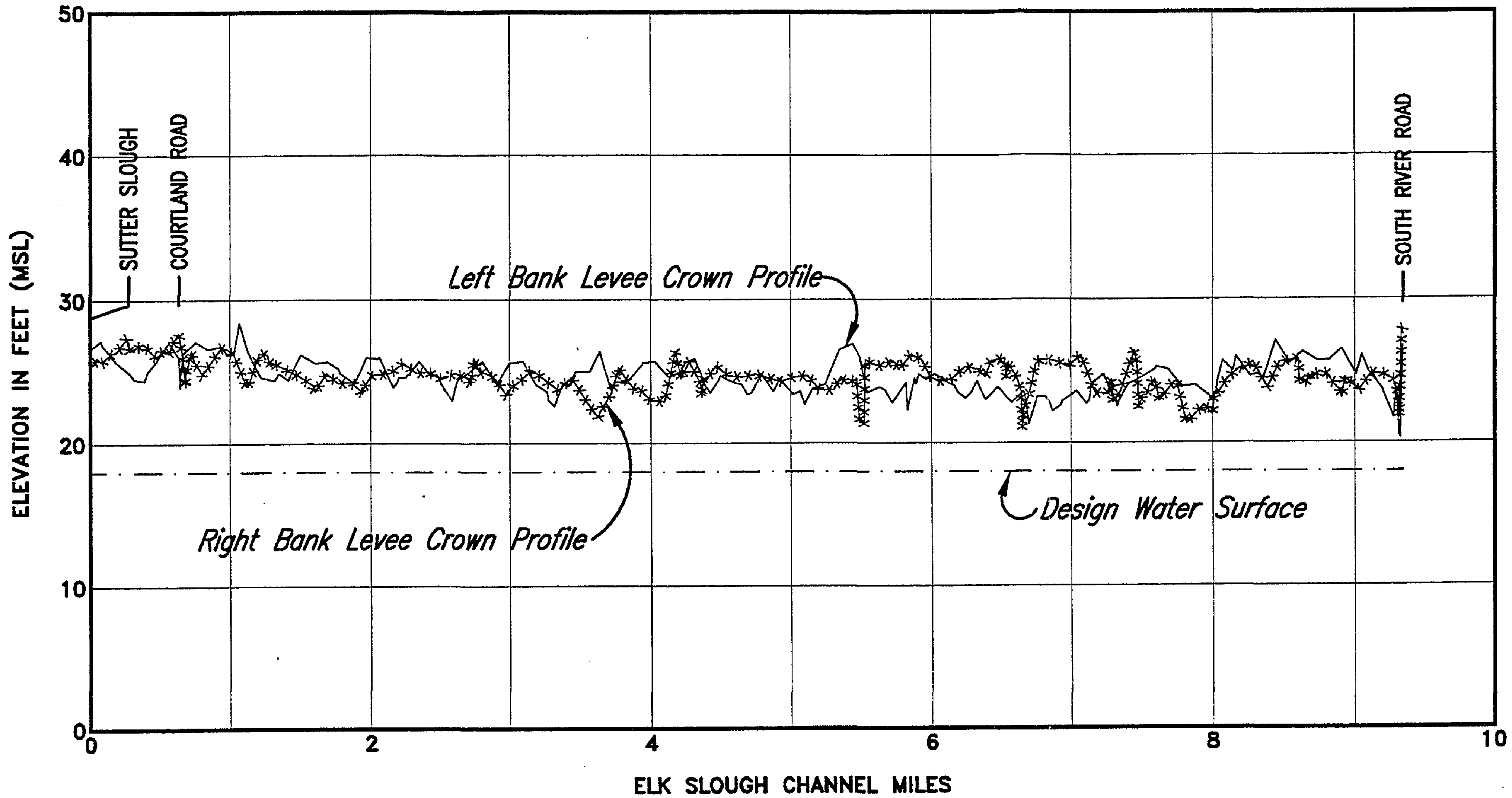
YOLO BYPASS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 9 Sheet 2 of 2

C-103507

C-103507



LEGEND

HIGH WATER MARK (FEBRUARY 1986)

STAGE RECORDER READING (FEBRUARY 1986)

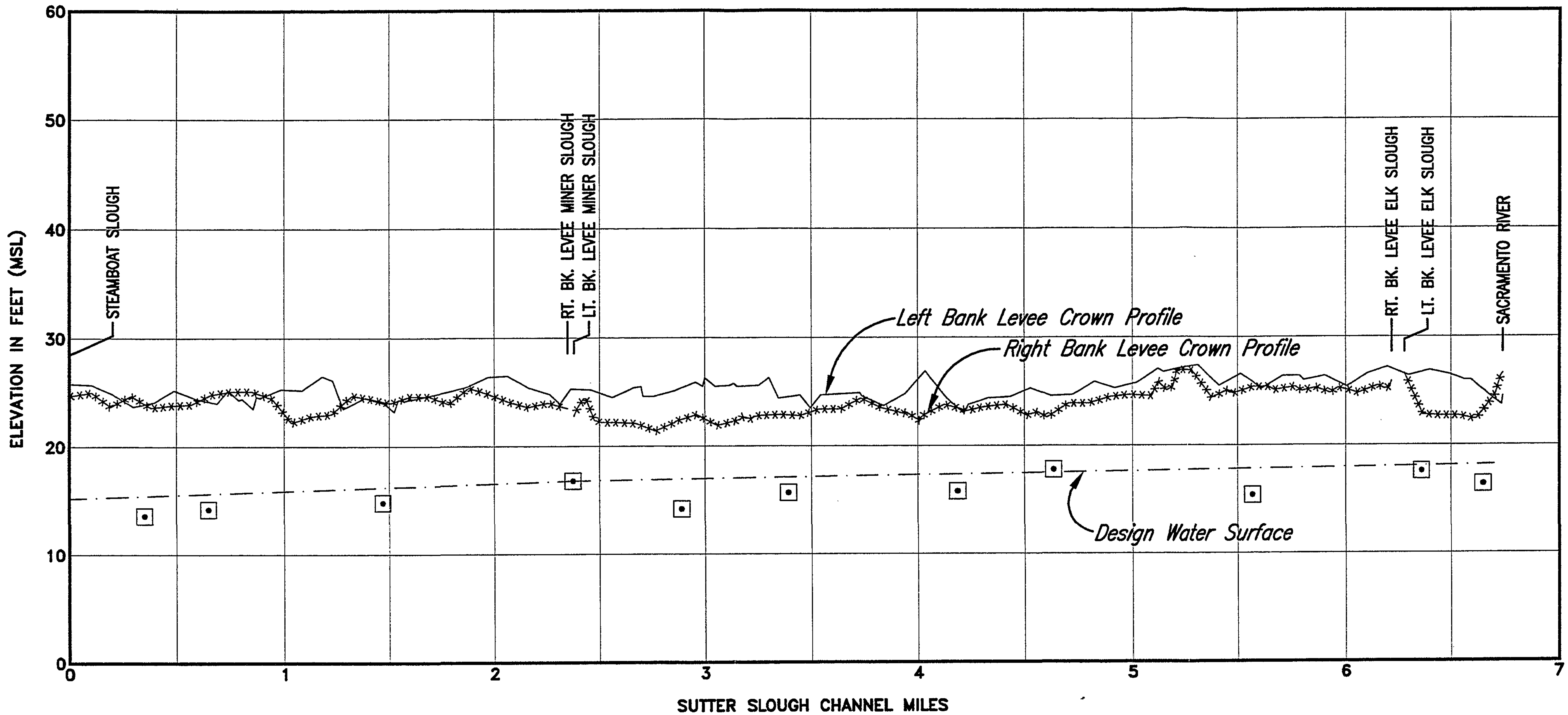
SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND WATER SURFACE PROFILES

ELK SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 10 Sheet 1 of 1



LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

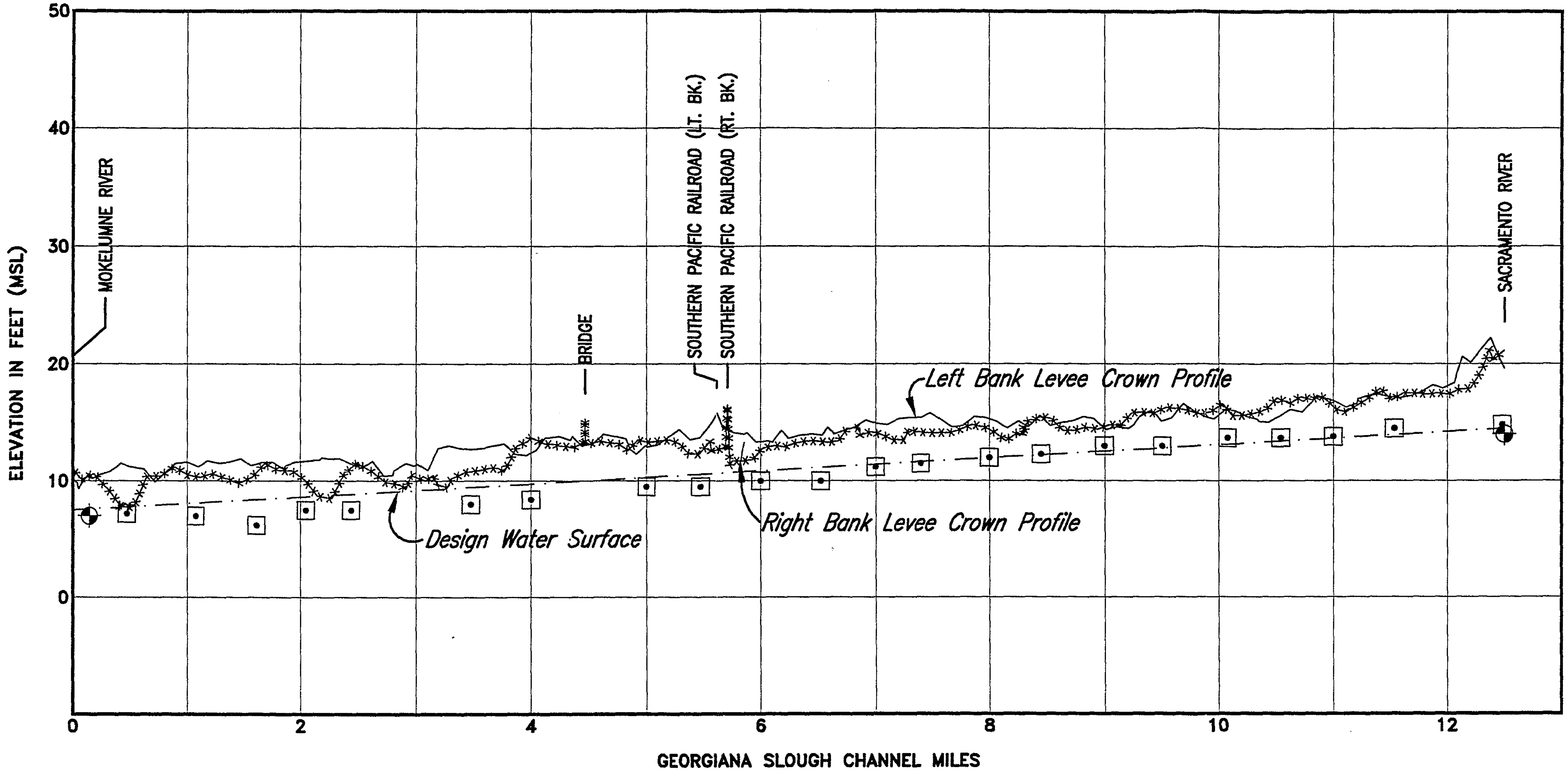
LEVEE CROWN AND WATER SURFACE PROFILES

SUTTER SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 11 Sheet 1 of 1

C-103509



LEGEND

HIGH WATER MARK (FEBRUARY 1986)

STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND WATER SURFACE PROFILES

GEORGIANA SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

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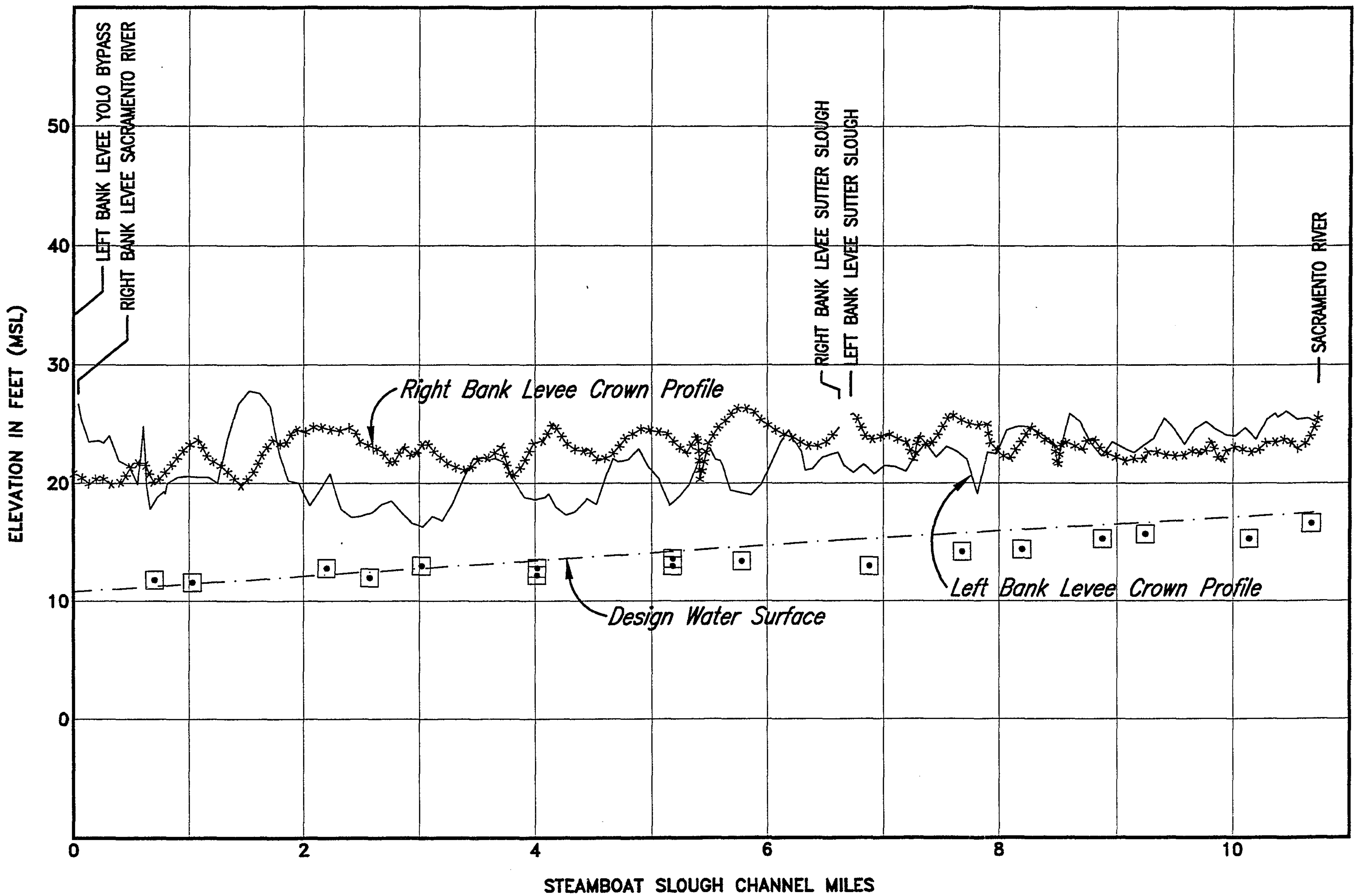
C-103510



LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND
WATER SURFACE PROFILES

STEAMBOAT SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

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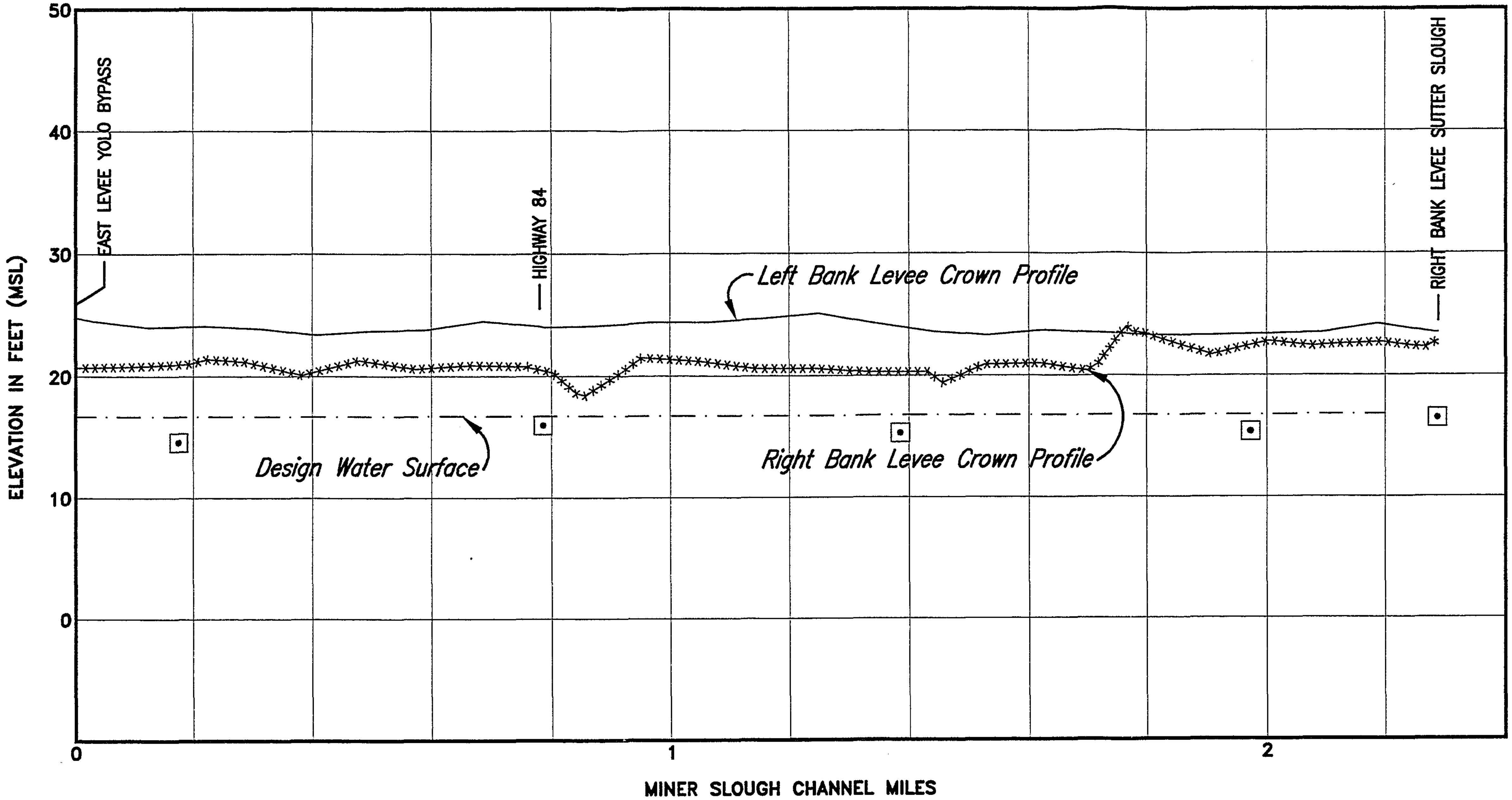
C-103511

C-103511



L E G E N D

HIGH WATER MARK (FEBRUARY 1986)

STAGE RECORDER READING (FEBRUARY 1986)

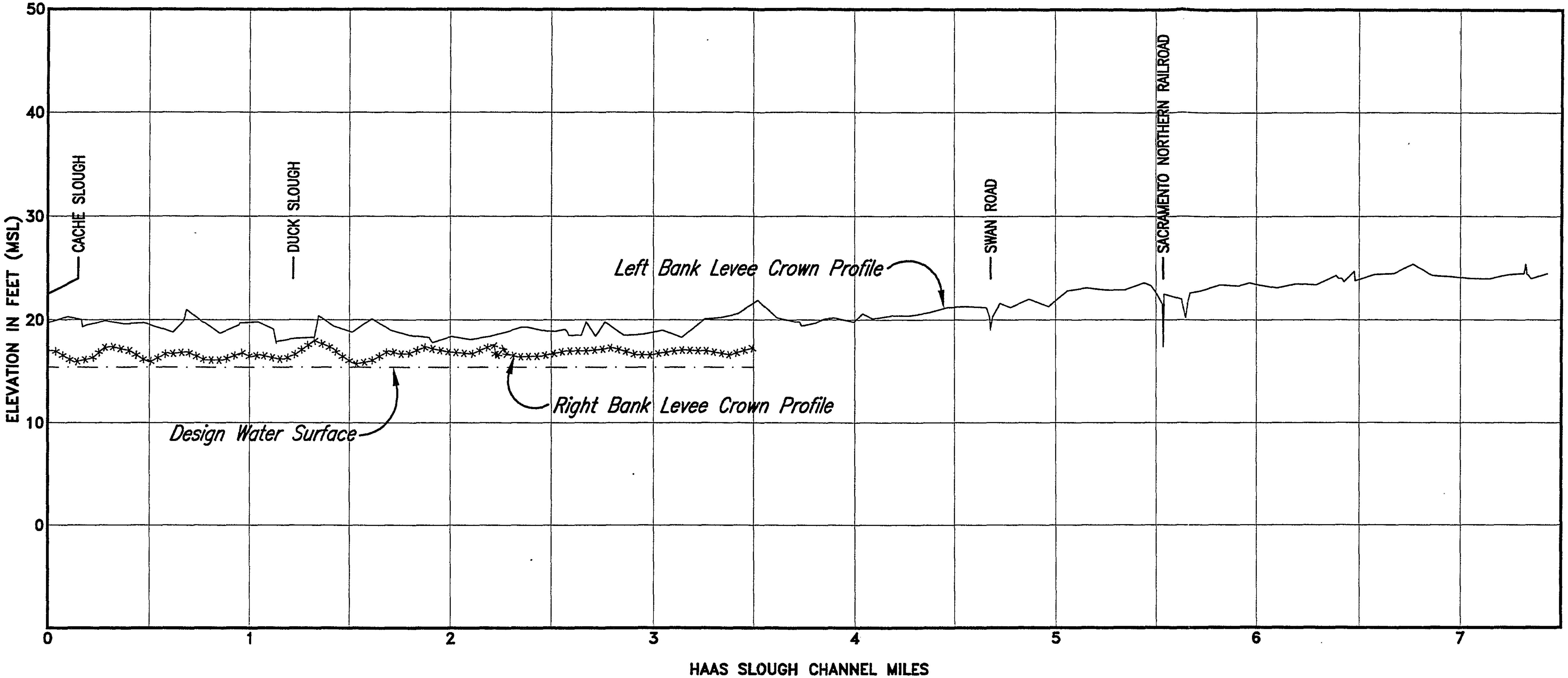
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND
WATER SURFACE PROFILES

MINER SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 14 Sheet 1 of 1



LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND
WATER SURFACE PROFILES

HAAS SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 15 Sheet 1 of 1

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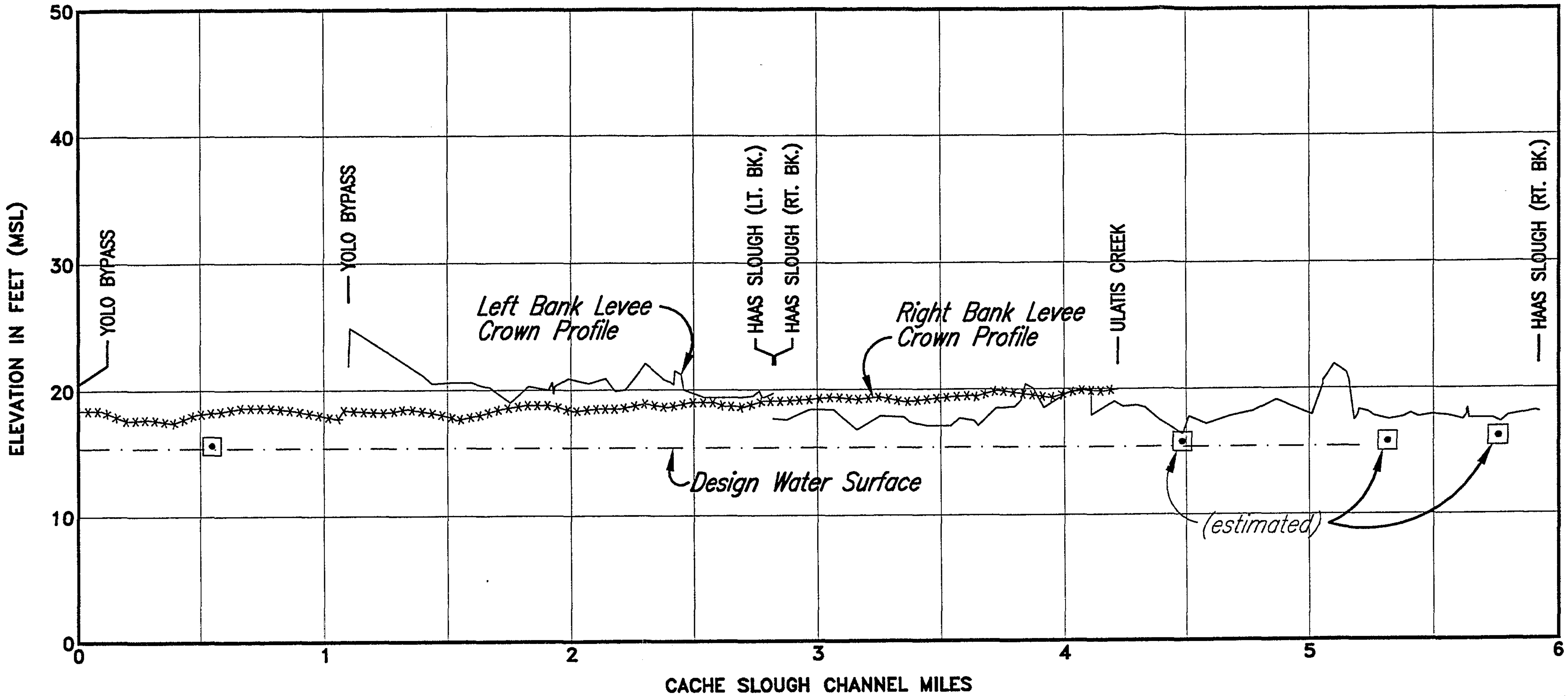


LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

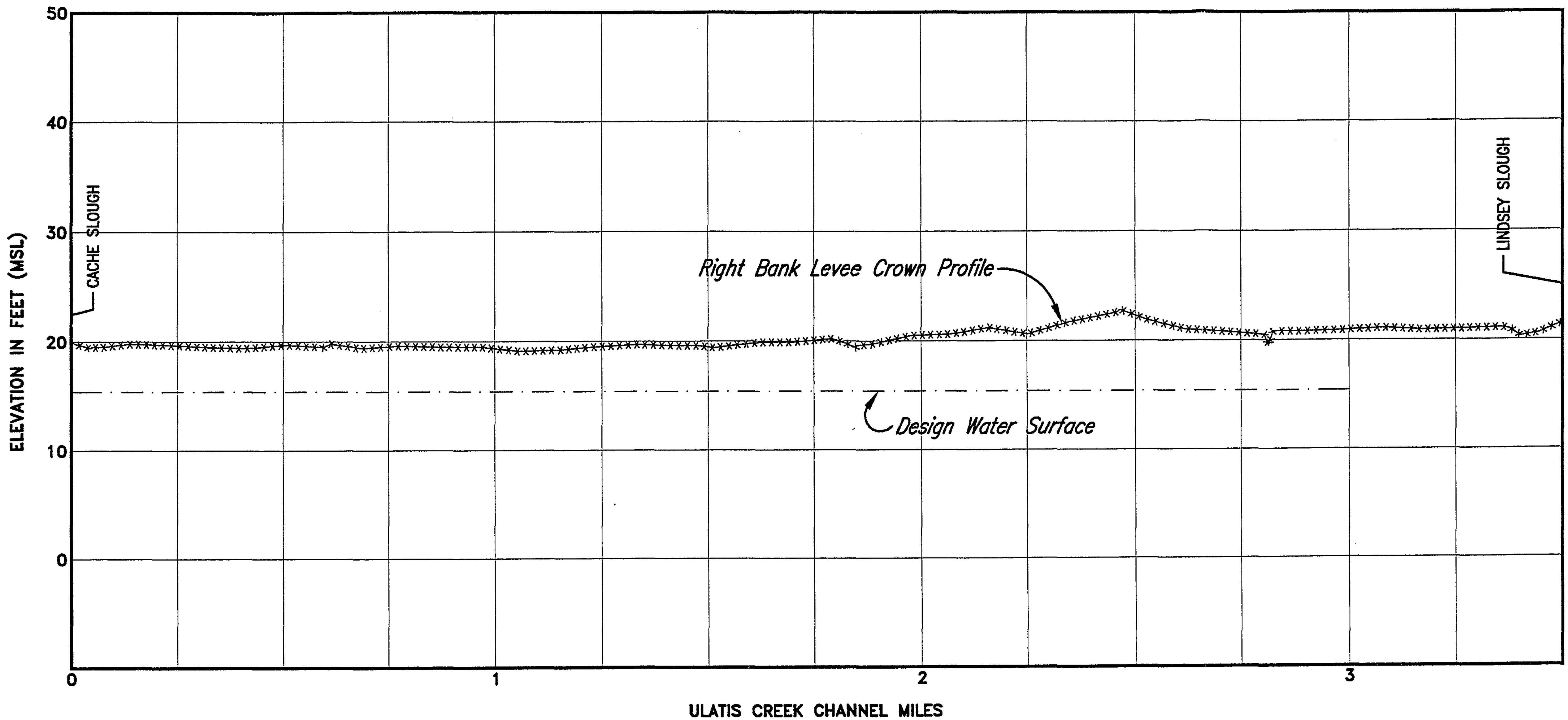
LEVEE CROWN AND WATER SURFACE PROFILES

CACHE SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 16 Sheet 1 of 1

C-103514



LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

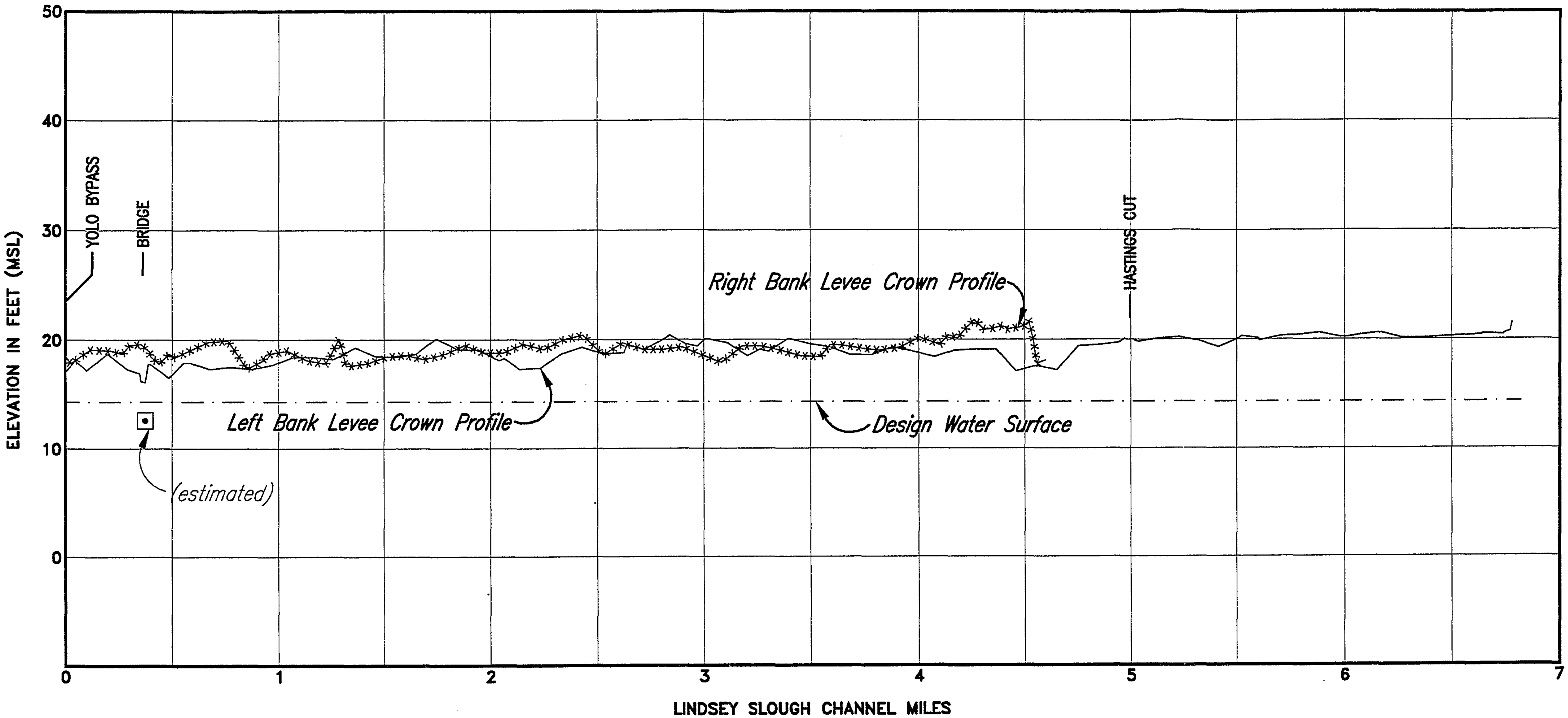
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND WATER SURFACE PROFILES

ULATIS CREEK

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 17 Sheet 1 of 1



L E G E N D

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND
WATER SURFACE PROFILES

LINDSEY SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

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C-103516

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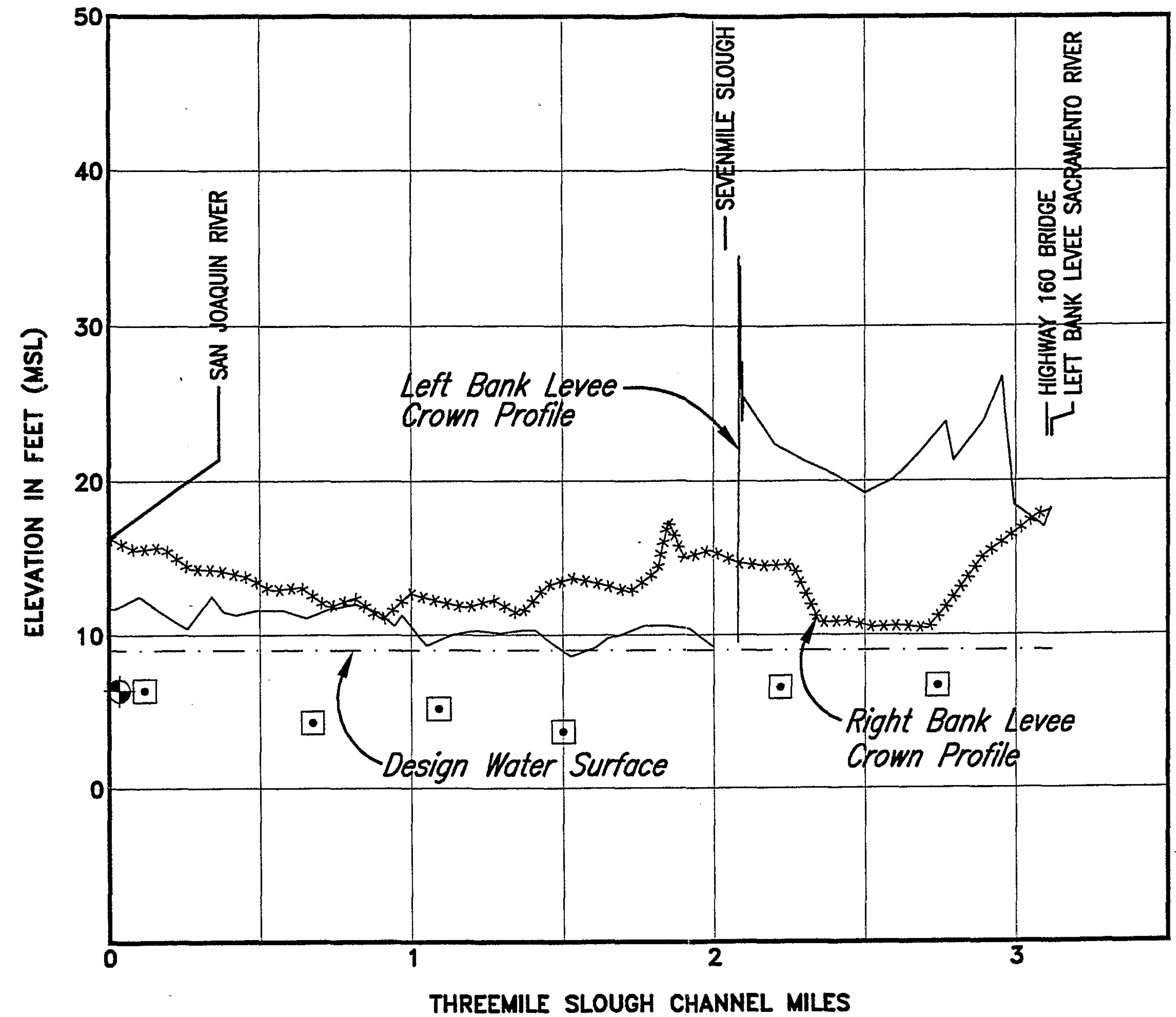

L E G E N D

HIGH WATER MARK (FEBRUARY 1986)

STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
LOWER SACRAMENTO AREA

LEVEE CROWN AND
WATER SURFACE PROFILES

THREEMILE SLOUGH

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 1993

PLATE 19 Sheet 1 of 1

C-103517

C-103517

Sacramento River Flood Control System Evaluation
Initial Appraisal Report - Lower Sacramento Area

Attachments